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BACTERIA OF SOIL AND PASTURE LEAVES AT CLAUDELANDS SHOWGROUNDS

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(*Received for publication, 25 February 1960*)

Summary

Leaf and soil samples from the Claudelands Showgrounds at Hamilton have been examined for seasonal changes and quantitative, taxonomic, and physiological differences.

The numbers of bacteria on the leaves are very much greater than in the soil and are commonly of the order of 100,000,000/g. wet weight. Numbers tend to be higher in summer and autumn and lower in winter and early spring. Conversely, the soil population tends to be lower in summer and higher in autumn, winter and spring.

Spore-forming bacteria form a major element of the soil flora, but are uncommon on leaves. Conversely, micrococci are far more common on leaves than in soil. Of the Gram-negative bacteria pigmented flavobacteria are dominant on leaves but not in soil. *Aerobacter cloacae* occurred both in soil and on the leaves but pigmented aerogenic fermenters also occurred on the leaves. Streptomyces are characteristically absent from the leaves.

The soil flora remained relatively unchanged throughout the year but the physiological character of the leaf flora showed marked seasonal changes particularly evident in the spring when the incidence of aerogenic fermenters rose sharply and there were appreciably fewer pigmented bacteria.

Despite the close physical proximity of the leaf and soil floras each preserves its integrity and its distinctive taxonomic and physiological character.

INTRODUCTION

Previous studies of grassland soils (Stout 1958, 1960) have revealed a soil flora commonly dominated by Gram-negative bacteria, particularly pseudomonads, and with an appreciable component of spore-forming bacteria. Some observations on tussock and herbage leaves have revealed a very different leaf flora. The present study was conceived to examine in greater detail the characteristics of the soil and leaf floras

respectively and of the relationship between the two. For this purpose a site was selected from which soil and leaf samples could be obtained throughout the year so that seasonal changes, both quantitative and qualitative, could be followed.

The site chosen was the Claudelands Showgrounds at Hamilton. The soil is the Horotiu sandy loam, an immature yellow-brown loam derived from mixed alluvium of rhyolitic and andesitic ash. This weakly weathered soil has a low cation-exchange capacity but a very high base saturation (cf. Table 1). Although under pasture of ryegrass and clover the Showgrounds were not subject to normal grazing practice although stock are grazed on it. Part of the area is used as an experimental area by the Ruakura Animal Research Station and the samples for the present study were taken from this experimental area.

TABLE 1. Chemical Analyses of Topsoil (½–2 in.) Samples

Samples	1	2	3	Mean
pH	5.9	5.6	5.9	5.8
Organic carbon %	4.2	3.7	4.1	4.0
Total nitrogen %	0.37	0.32	0.34	0.34
C/N.	11	12	12	12
Cation-exchange capacity me.%	12.7	10.9	11.7	11.8
Total exchangeable bases me.%	10.9	8.3	9.8	9.7
% Base saturation	86	76	84	82

Material and Methods

Although the principal study was of the Claudelands Showground site, other samples of herbage were examined from various parts of New Zealand for purposes of comparison.

Soil samples were collected from both the ½–2 in. level and 2–4 in. level. Generally five samples were collected at a time. A sod of turf was also brought down from Hamilton to the Soil Bureau Experimental Station at Taita and kept in the glasshouse and both the soil and the herbage examined.

Herbage was collected at all stages of growth and throughout the year. The condition of the herbage varied from fresh green shoots, to mature "hardened" green pasture, to brown dry hay. Many of the herbage samples were provided by the Ruakura Animal Research Station (particularly those from Claudelands, Rukuhia, and Matamata) and some of the samples had been tested for facial eczema toxicity (cf. di Menna 1959). These samples had necessarily to be held until the guinea pig feeding experiments had been carried out. Such samples were stored in deep freeze at temperatures from —15° to —20.5°C. Every effort was made to examine samples as quickly as possible after collection but in a number of cases some days delay necessarily intervened. The results suggest that in the case of herbage such delay does

permit a rapid expansion of the bacterial population and consequently the quantitative results obtained from such samples must be treated with caution.

The herbage generally consisted of predominantly ryegrass-clover pasture but pure stands of both ryegrass (*Lolium perenne*) and white clover (*Trifolium repens*) were also sampled.

Except for the Dunedin site and the white clover stand at Palmerston North, which were ungrazed, the herbage was grazed by sheep.

Soil dilutions were prepared in the ordinary way with sterile water.

Leaf dilutions were similarly prepared from 5 g of sample with sterile water, the first dilution being shaken intermittently for about 15 min before proceeding with serial dilutions. Alternatively some samples were prepared with 0.1% peptone as the diluent and others were macerated in a sterilised Townsend and Mercer top-drive macerator. The leaf dilutions were the same as those prepared by di Menna (1959) except that a larger series of dilutions was used for the bacterial plates.

Although counts were made for all samples studied and notes were taken of the general cultural characteristics of the flora, taxonomic work was concentrated on the Claudelands samples.

ISOLATION AND COUNTING

Dilution

It is well known that plate counts of successive soil dilutions do not present a linear series (Meiklejohn 1957). There tend to be relatively more colonies on plates prepared from higher dilutions than from those prepared from the lower dilutions. This may partly be accounted for by the more successful breaking up of clumps of bacteria at the higher dilutions and also by the lessened effect of antibiotic factors which are necessarily less effective at higher dilutions. Further, at higher dilutions where there are fewer colonies developing on the plates, they are less likely to be affected by mutual antagonisms. This phenomenon of relatively increased counts with successive dilutions, while common with soil dilutions, is also shown with dilutions prepared from herbage. To throw some light on this problem two aspects of the dilution technique were investigated, namely, the effect of the diluent and the effect of maceration of the herbage prior to preparing the dilution series.

Normally, sterile distilled water or sterile tap water are used as diluents. It has been suggested, however, that these are less favourable than diluents containing organic substances (Straka and Stokes 1957). In Table 2 is given the results of plate counts of two parallel dilution series prepared from the same herbage sample. In one case sterile tap water was used as a diluent and in the second 0.1% peptone was the diluent. It can be seen that there is no great difference between the two and that count variations cannot therefore be ascribed to the effects of the diluent.

The effects of maceration prior to dilution are much more dramatic. In Table 2 are shown the results of plate counts of two parallel dilutions

TABLE 2. PLATE COUNTS (x 10^6 per g wet weight) OF SOIL AND GRASS SAMPLES COLLECTED FROM CLAUDELANDS RACECOURSE ON 14 JANUARY 1958

Sample	Cultured 15 Jan. 1958			Cultured 16 Jul. 1958	
	Topsoil (0–2 in.)	Grass	Grass	Grass	Grass
Condition	Fresh			Stored in deep freeze for six months	
Dilution treatment	Shaken with water		Shaken with 0.1% peptone	Shaken with water	Macerated with water
Aerobic counts					
Glucose plates	0.9	430	320	80	600
Lactose plates	1.3	110	320	20	360
Bacillus plates	0.09	0.01			
Anaerobic counts					
Glucose plates	0.33	45	140		

All the grass counts given, except for the *Bacillus* count, were made on plates prepared from a dilution of 10^{-7}.

series both prepared from the same herbage sample, in one case the herbage having been macerated in a sterilised Townsend and Mercer macerator for two minutes before the dilutions were prepared. There is clearly a marked difference between the two series of plates and this difference can therefore be reasonably ascribed to the more successful breaking up of bacterial clumps by the macerator. A priori, it seems more reasonable to attribute to this physical factor the discrepancies between successive dilutions since the counts are made at very high dilutions at which antibiotic factors would be unlikely to operate. Further, streptomyces, the principal source of antibiotics, are typically absent from herbage samples. These results suggest that, high as they are, the counts obtained by the ordinary dilution method are substantially less than the actual number of bacteria present on the leaves.

Direct Examination

The very high counts occurring on dilution plates prepared from herbage rendered it desirable that some direct check should be made on the incidence of micro-organisms on the leaves. Two methods were employed. One involved stripping the epidermis off the leaf and mounting it on a slide for direct examination with transmitted light.* The second involved making an impression of the leaf's surface on a slide or on an agar plate by gently pressing the reverse surface with the back of a scalpel.

Both methods confirmed the very high concentrations of bacterial cells indicated by the plate counts. The bacteria tended to be grouped in clumps, particularly of short coccoid rods which were shown to be

* I am indebted to my colleague Dr Margaret di Menna for these preparations.

Gram-negative on the impression plates. Unlike the yeasts (di Menna 1959) the bacteria did not appear to be grouped around the edges of the epidermal cells or the stomata but were irregularly distributed over the leaf's surface.

Effect of Storage

The possibility that it would be necessary to examine samples of herbage that had been stored for some time led to an investigation of the effects of deep freeze on the herbage microflora. In Table 2 is given the comparative results obtained from a herbage sample examined fresh and after six months in deep freeze. In this case the numbers in the stored sample were appreciably less than in the fresh sample.

Isolation

In an endeavour to screen separately different physiological and taxonomic groups of bacteria, three different isolation techniques were employed.

In the first two, dilutions were prepared in the normal way with sterile water but two series of plates were prepared from each dilution. One, dextrose-tryptone-yeast extract agar (Stout 1958), permits the rapid growth of most heterotrophs. The second, consisting of lactose (1%), and difco yeast extract (0.1%) and agar (15%), was devised to allow more rapid growth of lactose-utilising bacteria. Initially brom-cresol-purple was added to the lactose plates to indicate acid production but it was found that the blue (alkaline) and yellow (acid) colonies isolated from these plates were identical and that both produced acid from lactose in liquid medium. The use of the dye was therefore abandoned.

The third technique involved heating the dilutions for 5 minutes at 80°c and then plating on DTY Agar.* This technique was intended to isolate spore-forming bacteria. Although there was a very great reduction in the number of colonies developing on these plates and although spore-forming bacteria tended to predominate, it was found that there were still a large number of non-spore-formers which survived the heat treatment (cf. Ross 1958). Nevertheless, this technique was considered to give a reasonable indication of the incidence of aerobic spore-forming bacteria.

RESULTS

Numbers of Bacteria

Herbage. In Table 3 is set out a brief description of the samples examined and a summary of the bacterial counts obtained.

The numbers of bacteria on herbage varies enormously and may range from the order of 10^4 to 10^{12} per gramme wet weight. Partly, these differences can be attributed to the time elapsing between collection of the sample and its culturing, and partly to differences in dilution technique. But there still remains with comparable samples similarly treated an enormous range in the size of the populations encountered. This enormous range of difference emphasises the most striking feature

* I am indebted to my colleague Dr D. J. Ross for preparing these plates.

TABLE 3. DESCRIPTION OF SAMPLES AND SUMMARY OF BACTERIAL COUNTS
Counts estimated per g wet weight

Date Collected	Claudeland's Samples Description	Other Grass Samples Locality Description	Date Cultured	Grass			Soil		
				Total Count (Glucose) Plates ($\times 10^6$)	Total Count (Lactose) Plates ($\times 10^6$)	Ratio Glucose/Lactose	Total Count Glucose Plates ($\times 10^6$)	Total Count Lactose Plates ($\times 10^6$)	Ratio Glucose/Lactose
1957			1957						
Feb. 21	Old dry grass, almost hay, and topsoil samples ($\frac{1}{2}$–2″)		Feb. 22	800			0.425		
Mar. 4	Young grass and topsoil ($\frac{1}{2}$–2″) from sod (collected February 21st) kept in glasshouse at Soil Bureau Experimental Station, Eastern Hutt Road, Lower Hutt.		Mar. 4	0.6	0.03	20	3.0	3.0	1
Mar. 12	(1) Young grass (1 day's growth), (2) green 7 day old growth, (3) brown 7 day old growth, and topsoil ($\frac{1}{2}$–2″).		Mar. 13	(1) 20.5 (2) 5.2 (3) 132	8 2.1 12	3.7 2.5 11	12.9	19.2	0.6
Mar. 16		Matamata kept in deep freeze, sampled July 2nd.	Jul. 4	19	5	3.8			
Jul. 2	Green grass (new growth), topsoil samples, (1) ($\frac{1}{2}$–2″) and (2) (2–4″).		Jul. 4	47.5	18	2.6	(1) 4.0 (2) 1.5	4.8 1.5	0.8 1.0

Aug. 8		Palmerston North (1) Pure Perennial Rye (2) Pure White Clover (3) Ryegrass-Clover from sod kept in glasshouse collected from Gisborne)	Aug. 9	(1)	25	37	0.7			
				(2)	25	84	0.3			
				(3)	15	22	0.7			
Oct. 22	Spring growth, topsoil samples ($\frac{1}{2}$–2″).		Oct. 23		82	85	0.96	4.0	4.6	0.9
1958			1958							
Jan. 14	Green summer growth, topsoil samples ($\frac{1}{2}$–2″).		Jan. 15		430	110	3.9	0.9	0.9	1
			Jul. 16		80*	20*				
					600*†	360*†				
Feb. 18	Green summer growth, topsoil samples ($\frac{1}{2}$–2″).		Feb. 19		170	30	5.7	0.14	0.37	0.4
Feb. 22		Rukuhia	Jul. 30		7,000,000*	4,000,000*	1.7			
Feb. 26		Dunedin	Feb. 27		31	31	1			
Mar. 13	Green grass, two samples.		Jul. 16	(1)	8,000*†	6,000*†	1.3			
				(2)	32,000*†	24,000*†	1.3			
Mar. 14		Rukuhia	Jul. 30		7,000*	2,000*	3.5			
Mar. 15	One sample of grass.		Jul. 30		700,000*	500,000*	1.4			
Mar. 19	Two samples of grass, (1) top level cut, (2) low level cut.		Mar. 27	(1)	23,000	2,500	9			
				(2)	220	10	22			
Mar. 24	One sample of grass.		Mar. 27		980	650	1.5			
Apr. 1		Dunedin	Apr. 5		6.7	6.6	1			
Apr. 29		Paraparaumu	Apr. 29		60	6	10			

* Sample held in deep freeze.

† Sample macerated.

of the herbage population, viz., its dramatic fluctuations in response to changing ecological conditions. Because of these dynamic changes it is however difficult to trace out the significance of the many ecological factors involved in determining the size of the bacterial population.

There is clearly a relationship between the age of the grass and the size of its population. For example, the three samples collected from Claudelands on 12 March 1957 included a sample of day-old growth with a population of 29 million, a sample of green week-old growth with a population of 5 million, and a sample of brown week-old growth with a population of 132 million. This suggests that favourable conditions for bacterial growth occur in the initial period of pasture growth, that this period is succeeded by somewhat less favourable conditions as the pasture "hardens", and that finally as the pasture dies off there is an exceedingly favourable period for bacterial growth. This interpretation is strengthened by the results from the samples collected from Claudelands on 19 March 1958. These two samples of mown grass represented the top-level cut of young growth and low-level cut of older growth and while the former had a count of the order of 10^{11} the latter had a count of only 10^{9}.

Apart from its influence on the condition of the herbage, the different kinds of pasture do not, in themselves, appear to influence greatly the bacterial populations. Thus samples taken at Palmerston North on 8 August 1957, from pure stands of perennial rye and white clover, had approximately the same numbers of bacteria.

Because of the decisive influence of the state of the herbage on bacterial numbers it is not possible to distinguish seasonal trends very readily but there does seem to be a trend to higher counts in the summer and autumn and to lower counts in winter and early spring. This in itself is rather a reflection of the response of plant growth to seasonal climatic changes than a direct response of the bacterial population, and that is shown by a lack of correlation between moisture and temperature readings and changes in bacterial numbers.

One very characteristic feature of herbage populations shown in the present survey is the virtual absence of spore-forming bacteria. On the plates prepared there were invariably few colonies and sometimes there were none. In relation to the enormous total counts, the *Bacillus* population was less than 0.1%.

A second feature of the herbage populations is the tendency for the counts on the glucose plates to exceed those on the lactose plates. This tendency was particularly pronounced in the summer and autumn samples but was reversed with the spring samples. The discrepancy between the glucose and lactose counts was less pronounced with samples that had been stored for a period and also disappeared if the plates were held for some days, indicating presumably adaptive utilisation of lactose (Table 4).

Soil. The numbers of bacteria in the soil samples taken directly from the Claudelands Racecourse ranged from 140,000/g wet weight to 4,700,000/g wet weight although counts from a turf kept for a week in

TABLE 4. LACTOSE ADAPTATION BY SOIL AND LEAF BACTERIA SUCCESSIVE COUNTS ON FRESH SOIL AND LEAF SAMPLES AND A STORED LEAF SAMPLE
Counts estimated ($\times 10^6$) per g wet weight

Sample	Date Collected 1957	Date Cultured 1957	1 day Count (25°C)			2 day Count (25°C)		
			Glucose	Lactose	Glucose / Lactose	Glucose	Lactose	Glucose / Lactose
Topsoil (½–2 in.)	Jul. 2	Jul. 4	4.5	2.2	2	4.0	4.8	0.8
Topsoil (2–4 in.)	Jul. 2	Jul. 4	1.3	0.3	.4	1.5	1.5	1.0
Green leaves	Jul. 2	Jul. 4	20	0.7	30	47.5	18.0	2.6
Green leaves	Mar. 16	Jul. 4	19	5	4	32.5	16.5	2.0

The three fresh samples were from Claudelands and the stored grass sample, which had been held in deep freeze, from Matamata.
The topsoil (½–2 in.) count is the average for five samples.

the glasshouse at Taita reached 19,200,000. The counts were higher in the winter and spring than in the summer and early autumn. The counts for the samples taken at a depth of ½–2 in. were higher than for the samples taken at about 2–4 in.

The counts on the *Bacillus* plates were also quite high, ranging from 25,000 to 400,000/g wet weight and constituting about 20% of the total count.

The count on the lactose plates was generally equal to or higher than the counts on the glucose plates.

(c) Relation of Soil to Herbage Counts

The populations of the soil and the herbage are essentially distinct both in their total numbers and in their seasonal fluctuations. This is illustrated quite clearly in Fig. 1 which shows the seasonal population trends of the soil and grass counts. The soil population, of which the spore-formers are an important part, is lowest in summer and highest in late autumn, winter, and spring. The leaf population, which has a negligible component of spore-formers, is highest in summer and lowest in winter and spring.

Generally, with the grass or herbage counts the ratio of glucose/lactose count is greater than 1 except in the winter and spring whereas for the soil counts the glucose/lactose ratio is often less than 1.

The proportion of colonies developing on glucose plates incubated anaerobically compared with those developing aerobically is of much the same order both in the case of soil and in the case of the herbage.

Taxonomic Character of the Flora

About 500 representative strains were isolated from the plates and of these 470 were put through various biochemical tests. Of these 470 isolates, 330 came from the dextrose and lactose plates: 187 were leaf

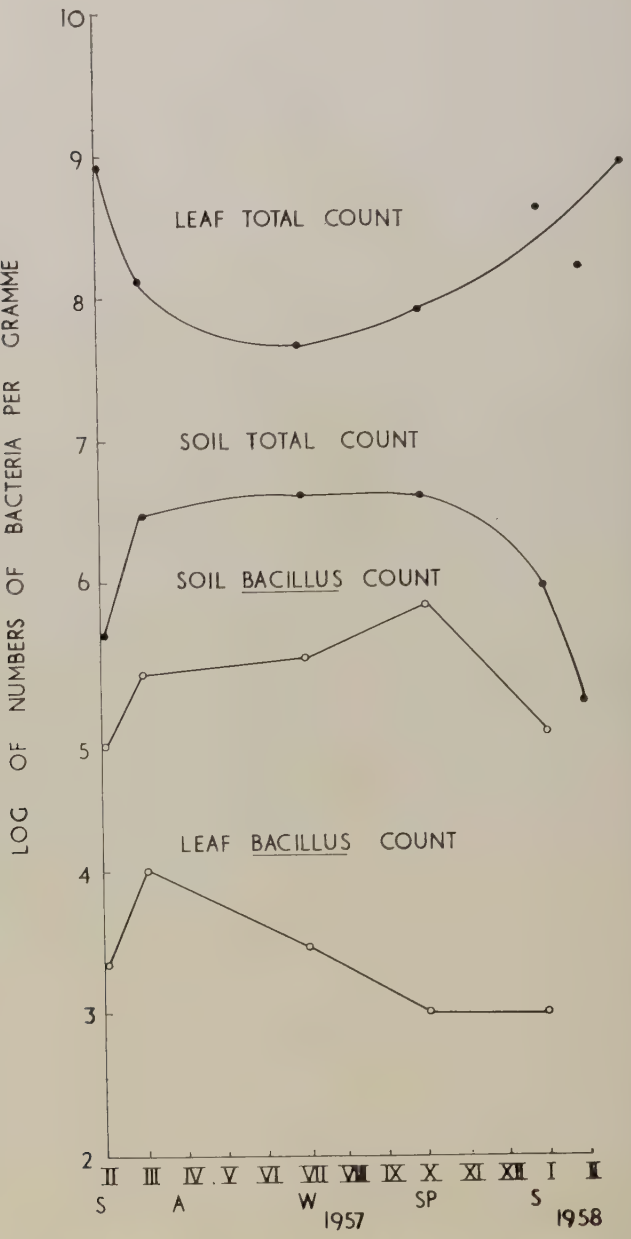

Fig. 1.—Total counts on DTY agar and on *Bacillus* plates for both leaves and soil.

isolates and 143 soil isolates. The remaining 140 isolates came from the pre-heated "*Bacillus*" plates and, of these, 75 were from the soil plates and 65 from the leaf plates.

Naturally, the majority of strains isolated from the pre-heated "*Bacillus*" plates proved to spore-forming bacilli, though a surprising number of non-spore-forming bacteria, especially micrococci, grew on the plates. *Bacillus* spp. were also, of course, isolated from the dextrose and lactose plates. Altogether 163 isolates were referred to this genus which comprised therefore about 37% of the total isolates. The proportion of soil to leaf isolates was roughly 2 : 1.

The second major group were the orange and yellow pigmented strains the majority of which were referred to the genus *Flavobacterium*. Orange pigmented strains, including aerogenic fermenters, numbered 94 isolates or 23% of the total. Yellow *Flavobacterium* represented another 4%. The proportion of soil to leaf isolates in this group was roughly 1 : 3.

A large number of isolates, about 60 or 15%, were pink to red in appearance. The flagellation of motile strains proved to be monotrichous. This group does not fit easily into any present taxon. They occurred in roughly equal numbers of soil and leaf isolates.

Less common isolates were *Acrobacter*, *Pseudomonas*, and *Micrococcus* each constituting about 4% to 6% of the total isolates; *Xanthomonas* forming only about 2% of the isolates and almost wholly from the leaves; and *Achromobacter*, *Chromobacterium*, and *Nocardia* of which a few strains were isolated in each case and which together formed less than 5% of the total isolates. About 2% of the isolates proved to be yeasts.

Although isolates were selected to give a fair representation of the kinds of colonial forms rather than of their proportionate numbers, the overall picture of the total isolates from the dextrose and lactose plates may be assumed to give a reasonable picture of the leaf and soil flora. The interpretation of the *Bacillus* flora, however, from the pre-heated "*Bacillus*" plates is perhaps less satisfactory (cf. Knight and Proom 1950) but the present evidence suggests that the overall picture —the overwhelming predominance of the *B. megaterium*, *B. cereus*, and *B. mycoides* group is not altogether misleading.

A summary of the taxonomic data is given in Table 5 which includes only finally identified strains of known leaf or soil origin. Following are some further notes on the individual taxa:

PSEUDOMONADACEAE

No pigmented types of *Pseudomonas* were observed on the plates. Strains isolated all failed to produce any characteristic pigment on the various media. Biochemically the strains were oxidative and generally proteolytic.

Yellow monotrichous strains isolated almost invariably from the leaves are referred to the genus *Xanthomonas*. These strains, which

TABLE 5. Taxonomic Summary Including Isolates Only of Known Origin

Taxa	Number of Isolates		%
	Soil	Leaf	
Pseudomonas			
Type IV	14	12	6
Xanthomonas	1	8	2
Flavobacterium			
Type I	26	61	21
Type II	3	14	4
Type IV*	1	6	2
?*Flavobacterium*	32	28	15
Chromobacterium	5	0	1
Achromobacter	2	2	1
Micrococcus	7**	9	4
Aerobacter	5	11	4
Bacillus	97	52	37
Nocardia	1	3	1
Yeasts	3	6	2
	197	212	100

* Aerogenic fermenters.
** Five of these isolates came from *Bacillus* plates.
The types refer to Stout (1958) and Stout (1960).

appeared to belong to a single taxon, produce acid from glucose aerobically but not anaerobically, and do not liquefy gelatin or peptonise litmus milk.

Rhizobiaceae

A few colonies of *Chromobacterium* occurred on the soil plates on one occasion (October 1957). They were never recorded from leaf plates.

Achromobacteriaceae

A few non-pigmented strains were referred to the genus *Achromobacter*. The great majority of strains isolated from the dextrose and lactose plates possessed yellow, orange, pink, or red pigmentation. While most of these pigmented strains, particularly the yellow and orange isolates, appeared to be typical members of the genus *Flavobacterium*, the position of the red and red-orange isolates is less certain. For convenience they are included here as *Flavobacterium* species until their correct identity is determined.

The great majority of isolates referred to the genus *Flavobacterium* produce on ordinary media a deep-yellow to orange growth and the colonies are characteristically raised, glistening, and mucoid. However, other colonial forms do occur, particularly non-mucoid wrinkled and adhering colonies, while occasionally on the initial agar plates the colonies are very thin with a metallic sheen. Both these colonial forms

revert to the mucoid type. This type is non-motile. Its biochemical characteristics are listed in a previous paper (Stout 1958; Table 2) under *Flavobacterium* Type I.

Culturally identical with this orange chromogen are a number of aerogenic fermenters. These are commonly treated as pigmented coliform bacteria, with which, biochemically, they have much in common (cf. Thomas and Hobson 1955). In the present survey they were isolated almost wholly from the leaves, whereas the non-pigmented fermenters were isolated from both leaves and soil. This suggests that they represent a separate taxon and it seems not irrational to associate them as a fermentative taxon of flavobacteria as *Aeromonas* is a fermentative taxon of pseudomonads. This group is motile with peritrichous flagellation. Biochemically they produce acid and gas aerobically and anaerobically from glucose and lactose, are V.P. positive, Indole negative, may or may not liquefy gelatin, produce an acid clot subsequently reduced in litmus milk, and give a positive Nessler's reaction when grown in tryptone broth.

Peritrichous yellow chromogens, previously recorded (Stout 1958; Table 2 *Flavobacterium* Type II), were also isolated chiefly from the leaves. They were far less common, however, than the non-motile orange type.

Occasionally deep orange colonies occurred almost hemispherical in side view, mucoid, glistening, and without any marked tendency to spread. This type produced acid from glucose aerobically but not anaerobically and did not liquefy gelatin. Although culturally and biochemically similar to the common *Flavobacterium* they proved to be motile with a single polar flagellum. Such flagellation is not, of course, characteristic of the genus and indeed is typically pseudomonad. However, the only pseudomonad genus in which they might be included is *Xanthomonas* but the cultural form is quite distinct from a typical *Xanthomonas*.

Besides these orange pigmented forms there were a large number of pink, red, and orange-red colonies. The intensity and range of the pigmentation varied with cultural conditions and it is difficult to determine how many taxa are involved. Growth may be limited with a tendency to form small discrete colonies, or alternatively there may be profuse growth. Biochemically they produce acid from glucose and often lactose aerobically, can grow in basal salts medium, may turn litmus milk acid, but do not liquefy gelatin. Motile strains have single polar flagella. Like the anomalous orange polar flagellate strains this group, probably heterogeneous, is of uncertain systematic affinities.

Enterobacteriaceae

If the orange fermentative taxa are referred to the Achromobacteriaceae there are left only cream or white isolates to be classed as coliforms. They were all lactose fermenters, V.P. positive and generally producing an acid clot in litmus milk. About equal numbers of gelatin liquefiers and non-liquefiers were recorded, but the strains were generally motile and are probably best referred to *Cloaca cloacae* (*Aerobacter cloacae*).

Micrococcaceae

A number of strains were isolated from the leaves and soil, in the latter case chiefly from the "*Bacillus*" plates. Cream, yellow, and orange colonies were isolated, the cells occurring single, in short chains or clusters, and rarely in tetrads but never in packets. Consequently, following Bergey (1957) they are to be referred to the genus *Micrococcus*. They were biochemically inactive, strict aerobes but able to use ammonium as a sole source of nitrogen and may produce an acid proteolysis of litmus milk. Some orange-red and red colonies which failed to sub-culture may also have been micrococci.

Bacillaceae

Of these isolates, 43% were *B. cereus*, 4% *B. mycoides*, and 35% *B. megaterium*. *B. cereus* occurred in three colonial forms, two rough and one smooth. The rough forms were both flat, dull, spreading with occasional whip-like outgrowths, but one form had a dull red pigmentation while the other was the normal white. Although roughly equal numbers of strains were isolated from leaves and soil there were almost twice as many pigmented forms from the leaves as from the soils. The smooth colonial form was entirely different from the rough and may have been asporogenous. It did not occur on the "*Bacillus*" plates, but was recorded on a few occasions from the lactose plates. The colony was raised, mucoid, translucent and glistening and on immediate sub-culture gave profuse, accumulating growth. On subsequent sub-culture it either reverted directly to the rough (white) form or passed through a stage of flat tough, adherent growth and then reverted to the rough white form.

Only a few colonies of *B. mycoides* were isolated as the characteristic colonial growth permits immediate identification. They were however about as common as *B. cereus* on the soil plates and at times were the dominant *Bacillus*. They were less common on the leaf plates where *B. cereus* was the typical dominant.

B. megaterium similarly tended to be dominant in the soil with few colonies isolated from the leaves.

Of the remaining isolates, 11% appeared to be nearest to *B. sphaericus*, three soil strains were referred to *B. polymyxa* and there were a few strains of *B. subtilis* and *B. pumilus* and a single strain of *B. circulans*. They were mostly derived from the soil plates though a few, including the *B. circulans*, were leaf isolates.

Actinomycetaceae

Only four strains of *Nocardia* were isolated, three apparently *N. corallina*.

Streptomyces although they were not isolated for taxonomic study were common on the soil plates occurring in numbers up to hundreds of thousands per gramme wet weight, but they were conspicuously absent from the leaf plates.

Physiological Character of the Floras

Generally, the leaf flora is distinguished by the predominance of pigmented forms, commonly orange, orange-red, or yellow, and presumed to be carotenoid. These may form up to 95% of the total number of colonies developing on the plates although the proportion may be as low as 20% in the spring or summer. The proportion of pigmented colonies was higher (75%) in the top-level cut of 19 March 1958 than in the low-level cut (40%) which suggests that the pigmented types tend to predominate where the grass is most exposed to the light. They diminish both proportionately and in total number in the soil with increasing depth. Thus, for the samples of 9 July 1957, the proportion of pigmented colonies on the grass plates was 55%, on the upper-topsoil plates was 22%, and on the lower-topsoil plates 7%. The total count of the upper topsoil was only about one tenth of the grass count and that of the lower topsoil only a sixth of the upper topsoil so that the proportionate numbers of pigmented types was of the order of 500 : 20 : 1. Of the strains isolated from the leaves off the dextrose and lactose plates 59% were pigmented whereas only 23% of the soil isolates were pigmented. This distinction is in agreement with the view that the carotenoid pigments have a protective role against the effects of visible light (Stanier and Cohen-Bazire 1957) and is the major physiological distinction between the leaf and soil floras (Stout 1960).

Analysis of the glucose metabolism of the strains tested shows little difference between the leaf and soil isolates (cf. Table 6) from the dextrose and lactose plates. Almost three-quarters of both the soil and leaf isolates produced acid, and only 7% of the soil isolates and 9% of the leaf isolates proved to be aerogenic fermenters. This proportion of aerogenic fermenters (7%) is low for grassland soil and may be associated with the low organic content (4% total carbon) of the soil (cf. Stout 1958, pp. 951-2). The proportion of aerogenic fermenters in the soil isolates remained fairly constant throughout the year but in the spring the proportion of aerogenic fermenters from leaf plates showed a dramatic increase forming 24% of the total isolates of 22 October 1957. This increase in fermenters was associated with the marked diminution, previously mentioned, in the incidence of pigmented types and is correlated with the fact that the fermenters were *Aerobacter cloacae*.

Proteolytic activity of the leaf and soil isolates is summarised in Table 6. Again there is little difference between the two, although the soil isolates tend to be more actively proteolytic than the leaf isolates, particularly against gelatin. However, compared with the flora of other grassland soils (Stout 1958) the proportion of proteolytic isolates is relatively low. Twenty leaf isolates were inoculated on egg albumen slopes since it had previously been found that some leaf strains were able to decompose this protein. After six months only three showed liquefaction of the egg albumen although fourteen had produced hydrogen sulphide.

Of the *Bacillus* strains tested, though there were fewer aerogenic fermenters the proportion of the different physiological groups was not very different from that of the non-sporing bacteria (Table 6).

TABLE 6. PHYSIOLOGICAL CHARACTER OF ISOLATES

Glucose Metabolism

Reaction in glucose broth with brom-thymol-blue as indicator.
Isolates from dextrose and lactose plates and *Bacillus* isolates.

	A & G	A	n.c.	Alk
Leaf isolates %	9	72	14	5
Soil isolates %	7	74	12	7
Bacillus isolates %	3	68		29

Proteolysis

Reaction in litmus milk.
Isolates from dextrose and lactose plates.

	RP	RC	A	Alk	n.c.
Leaf isolates %	7	5	76	—	12
Soil isolates %	14	3	64	8	11

Reaction in gelatin.
Isolates from dextrose and lactose plates.

	A	B	C	D	E	F
Leaf isolates %	52	15	6	10	2	15
Soil isolates %	38	16	16	7	10	13

Glucose metabolism: 1% sugar, 1% Bacto-tryptone, brom-thymol-blue; A, acid; A & G, acid and gas; Alk, alkaline; n.c., no change.

Litmus milk: P, peptonized; C, clotted; R, reduced; A, acid; Alk, alkaline; n.c., no change.

Gelatin: A, filiform growth (no liquefaction); B, crateriform; C, napiform; D, infundibuliform; E, saccate; F, stratiform.

DISCUSSIONS AND CONCLUSIONS

The flora of grassland soils previously studied (Stout 1958) was dominated by pseudomonads and particularly *Ps. fluorescens*. The absence of *Ps. fluorescens* and the reduced importance of pseudomonads in the flora of the present soil make it by comparison not a characteristic flora of grassland soil. Similarly, the proportion of aerogenic fermenters is lower than in previously studied soils. The general diminution of the Gram-negative bacteria may be attributed in part to the history and present state of this soil. Although classified as a Horotiu sandy loam the present site differs profoundly from the mode. For example, the organic carbon of a typical profile (N.Z. Soil Bureau 1954) is about 20% whereas the organic carbon of the present soil is only 4%. While the present site has been clear of forest for a considerable period it has not been subjected to ordinary agricultural practice but to the diverse

purposes of a showground. The Gram-negative bacteria appear to be largely dependent upon root development and the accumulation of soil organic matter and it would seem in this respect that the present site has not proved particularly favourable. The diminution of the Gram-negative flora emphasises the importance of spore-forming bacteria, which do not appear to be less numerous than in previously studied soils. It is clear that these bacteria are less exacting in their ecological requirements.

The leaf flora resembles the leaf flora previously studied (Stout 1960) in the predominance of pigmented types and in the incidence of micrococci. The present study has also shown that few spore-forming bacteria are found on leaves, a finding supported by other evidence (Gibson *et al.* 1958). Physiologically, the present flora differs from that previously examined, particularly the tussock leaf flora, in the incidence of fermenters and greater saccharolytic and proteolytic activity. This is no doubt attributable to the differences in the kind and condition of the leaves. The tussock leaves are dry and slow growing, and decay little above ground. The pasture leaves are moist and lush with a rapid cycle of growth and decay. Most Gram-negative bacteria require a relative humidity of at least 94% for growth (Scott 1957) so that the moister conditions of the pasture leaves are far more favourable for their growth than the dry tussock leaves. Further it seems likely that leaf exudates are richer and more frequent with the fast-growing pasture plants than with the tussocks. The results also suggest that not only are there significant ecological differences between plant and plant but also that the same plant may offer different conditions at different seasons or under varying growth conditions. So, for example, the higher incidence of aerogenic fermenters and the diminution of the pigmented types in the spring leaf samples may reasonably be attributed to differences in the herbage at this time of year. Similarly, marked quantitative differences in samples taken at the same time can be correlated with the different growth stages of the herbage, for example, the differences between the young green leaves and the brown decaying herbage collected in March 1957.

Quantitatively, the leaf population is very much greater than the soil population. Since there must be continual elution from the leaf surface through the soil one might expect the topsoil to be extensively contaminated with the leaf bacteria. Surprisingly, such contamination is not as extensive as might be envisaged. The integrity of the soil flora is preserved even in the apparently depleted condition of the present soil flora. The leaf forms show a heavy mortality with increasing soil depth. Plainly there are positive environmental factors militating against the survival of the leaf forms in soil. Equally clearly, the soil forms which have, apparently, every opportunity to colonise the growing leaves appear unable to establish themselves in this environment. There are surprisingly few taxa which appear to be successful in both niches. One important difference between the two floras is the apparent absence of streptomyces from leaves. Should the leaf flora be sensitive to the antibiotic activity of the soil streptomyces their exclusion from this habitat would be less surprising. Similarly, should the soil prove sensitive

to either visible or ultra-violet light their absence from the leaf surfaces would be explained. At present, however, insufficient evidence is available to establish either of these hypotheses, attractive as they both may be. All that is established is the differences between the two floras: quantitative, taxonomic, and physiological.

Acknowledgments

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THE OCCURRENCE OF AGRICULTURAL DROUGHT AT ASHBURTON, NEW ZEALAND

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Summary

Agricultural drought is defined as existing when the soil moisture in the root zone is at, or below, the permanent wilting percentage. The condition continues until rain falls in excess of the daily evapotranspiration. The occurrence of agricultural drought at Ashburton was calculated for 44 seasons, using Thornthwaite's method of estimating changes in soil moisture.

Agricultural drought occurred in every season studied, ranging from 107 days (1931-32) to 6 days (1944-45). The average number of drought days was 59. Nearly 60% of all days of drought occurred in spells of 10 consecutive days or more.

The data obtained gave no indication of any periodicity in the occurrence of drought.

The seasonal production of pasture and lucerne was negatively correlated with the total number of days of drought in a season, the correlation coefficients being —0.91 for lucerne, and —0.92, —0.58 and —0.95 for pasture measured from three experiments.

Introduction

Rainfall in New Zealand does not vary greatly from year to year, and is, generally, reasonably well distributed throughout the year. Some regions, however, particularly in the South Island, experience on occasions moderate to severe dry periods. These dry periods can cause considerable loss of farming production: for example, prolonged dry weather during the 1958-59 season had a near-disastrous effect on many farmers in Banks Peninsula and Marlborough. Drought, therefore, is probably the most important of the natural hazards affecting farming in New Zealand. In many places it is also the one climatic extreme which can be, at least partially, overcome—by irrigation. It is important, therefore, that the likely occurrence, distribution, and effect of drought be studied.

Thornthwaite and Mather (1955) have listed four types of drought:

(1) Permanent Drought: driest climate, no agriculture without irrigation;
(2) Seasonal Drought: areas with well-defined rainy and dry seasons:
(3) Contingent Drought: depending on the irregularity of rainfall and occurring in sub-humid and humid climates;
(4) Invisible Drought: where rain does not equal evapotranspiration (most regions).

The value of number (4), invisible drought, is doubtful: the term 'drought' should be confined to fairly serious moisture deficits. Contingent droughts are the main concern in New Zealand and the present

study was undertaken to determine the frequency, duration, and agricultural significance of such droughts at Ashburton.

Dry periods and periods of low rainfall in New Zealand have been described by Kidson (1931) and drought by Bondy (1950). In the latter, the generally accepted definitions of drought have been used. These are:

An *absolute drought* is a period of at least 15 consecutive days, to none of which is credited 0.01 in. or more of rain.

A *dry spell* is a period of at least 15 consecutive days, to none of which is credited 0.04 in. or more of rain.

A *partial drought* is a period of at least 29 consecutive days, during which the mean daily rainfall does not exceed 0.01 in. per day.

Rainfall has been used as the basis for determining the occurrence of drought mainly because it is easily measured and information on it is readily available. It will be realised, however, that such definitions may bear little relationship to drought as experienced in agriculture, for we are here concerned with the growing plant and its moisture supply. Fifteen consecutive days without rain in mid winter in Canterbury would probably result in only a slight lowering of the percentage of moisture in the soil from field capacity, but the same rainless period in mid summer may bring the soil from field capacity to close to the permanent wilting percentage. At this point a fall of rain of 0.01 in. would technically break the 'drought' but would have no effect on the dry soil.

An accurate definition of agricultural drought, therefore, should take into consideration the moisture state of the soil, and its effect on plant growth. Van Bavel and Verlinden (1956) have defined agricultural drought as "a condition in which there is insufficient soil moisture available to a crop". They further define a "drought-day" as a period of one day during which the drought condition occurs.

Whether soil moisture can be said to be sufficient or insufficient for plant growth depends on a knowledge of the characteristics of the soil and the crop being considered. This definition has thus deliberately refrained from describing what is meant by "insufficient soil moisture" because of a lack of data which would enable this to be done. In the present investigation enough information was available to enable the definition to be re-phrased:

"Agricultural drought exists when the soil moisture in the root zone is at, or below, the permanent wilting percentage. The condition continues until rain falls in excess of the daily evapotranspiration."

This covers only fairly severe droughts, as crop or pasture growth will probably be adversely affected before the permanent wilting percentage is reached. However, there exists some difference of opinion as to the relative availability of soil moisture over the range from field capacity to permanent wilting percentage (and this may vary between different soils) while there is general agreement that plant growth does not occur below the permanent wilting percentage.

The above definition implies a knowledge of changes in soil moisture conditions, and such records are rare. If, therefore, dependence were placed on the availability of reliable soil moisture data, the definition would have extremely restricted application. There are, however, methods available for estimating daily evapotranspiration values, and these can be used to calculate changes in the moisture level in the soil. The Thornthwaite (1948) method has been used in such drought studies by Van Bavel (1953), the Penman (1948) method by Van Bavel and Verlinden (1956) and Van Bavel and Carreker (1957) and the Blaney-Criddle method by Palmer (1958).

Rickard (1957) has shown that Thornthwaite's method was reliable for local conditions, and it was therefore used. It has the advantages of simplicity and requires only daily rainfall and mean temperatures. These were available from 1912-13, and the survey of drought covered the period from then to 1955–56—a total of 44 seasons.

METHODS

Changes in soil moisture levels were calculated from 1 September to 30 April, using mean daily values of evapotranspiration for each month, and daily rainfall figures. Changes in soil moisture were calculated until a deficit of 2.04 in. was obtained, corresponding to permanent wilting percentage in the top 12 in. of the Lismore stony silt loam. This soil type, which is representative of a large area of Canterbury, has an average depth of 12–14 in. A root-zone depth of 12 in. is therefore reasonable for the pastures and crops grown.

Once a deficit corresponding to the permanent wilting percentage was obtained, each subsequent day was a day of agricultural drought until rain fell in excess of the daily evapotranspiration rate.

The total number of days of agricultural drought for each month and each season, and the occurrence and duration of periods of 10 or more consecutive days of agricultural drought in each season was obtained.

RESULTS

Occurrence of Agricultural Drought

The total number of days of drought in each season varied from 107 (1931-32) to 6 (1944-45) with a mean of 59. The average distribution throughout the season is shown in Table 1. At the beginning of the season (1 September) the soil is at field capacity, holding just over 2 in. available water in the top 12 in. of soil. The average total evapotranspiration for September is 1.5 in. so that, even with completely rainless conditions, there is insufficient evapotranspiration to deplete the moisture held in the soil. A mean rainfall of 2.49 in. during September means that usually the accumulated loss by evapotranspiration by the end of September is not great, and October, therefore, generally commences with a reasonable store of moisture in the soil. Consequently, drought conditions never occur during September and only occasionally in October. The rate of evapotranspiration is high during December to March, and 80% of the total number of days of

drought occur in these months. January and February are the two driest months.

TABLE 1. Distribution of Days of Agricultural Drought Month by Month

Month	Total Number of Days of Agricultural Drought—44 Seasons	% of Total
September	nil	—
October	9	0.3
November	206	7.9
December	469	18.0
January	576	22.2
February	529	20.4
March	477	18.3
April	333	12.8
Total	2599	99.9
Mean	59	

TABLE 2. Classification of Seasons Based on Total Number of Days of Drought

No. of Days of Drought	Description	No. of Seasons	% of Total Seasons
90	very dry	5	11.4
61–90	dry	18	40.9
31–60	moderately dry	12	27.3
16–30	wet	6	13.6
0–15	very wet	3	6.8
	Total	44	100.0

The total number of days of drought in any particular season is a measure of the degree of dryness of that season, and provides a basis for the classification of seasons. This is shown in Table 2. In 52% of all seasons, the days of drought exceeded 61 or a total of approximately 2 months. More seasons fall in the "dry" division (61–90 days) than any other. The frequency distribution of drought days in groups of 10 is given in Fig. 1: this shows that in 75% of all seasons, the number of days of drought is greater than 40, in 52% greater than 60 and in 25% greater than 80.

Although the total number of drought days in a season is of importance, it is the duration of consecutive drought days which offers the greatest hazard to farming. A continuous period of 10 or more days of drought is a severe check to crop or pasture production, particularly as it occurs after a relatively rainless period. During the 44 seasons studied, there were 90 such periods, as many as five in one

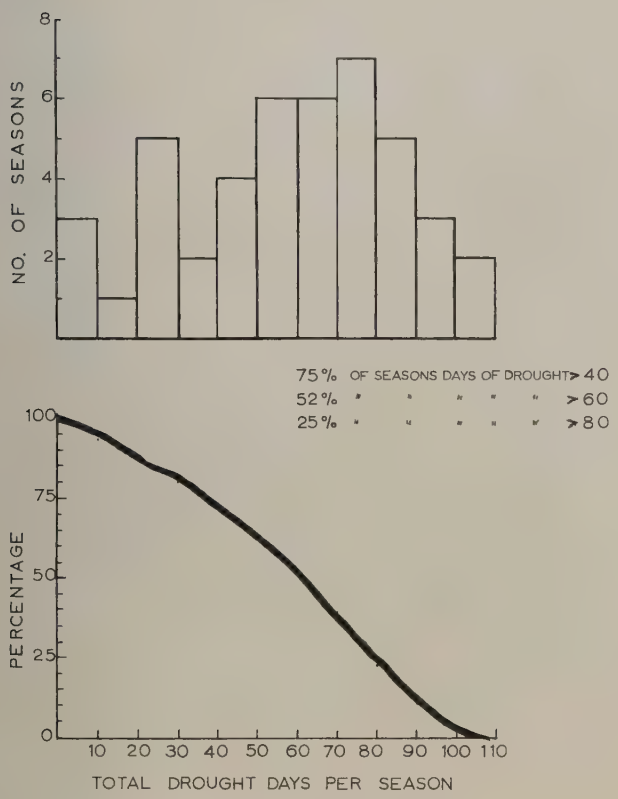

Fig. 1.—Frequency distribution of drought days.

season (1923-24, 1954-55), and ranging up to 42 days duration (28 Nov. 1916 to 8 Jan. 1917). Nearly 60% of all days of drought occurred in spells of 10 consecutive days or more. The seasonal distribution and length of such periods for the 44 seasons is given in Fig. 2. Such periods only occasionally occur in November and can occur up to the end of April and—in two cases—even in May. It can be seen from Fig. 2 that periods of drought are frequently followed within a few days by another drought period. For example, during the 1938-39 season, a drought existed from 11 to 22 January. This was technically broken by 13 points of rain on January 23, and drought conditions existed from 24 January to 5 February. Again, 61 points of rain on February 6 interrupted the drought until February 11. This last period of drought lated until 7 March. It is extremely unlikely that the two falls of rain would confer much practical advantage on a pasture or crop, and the effective total of consecutive drought days in this case was at least 56 days. As the commencement of agricultural drought

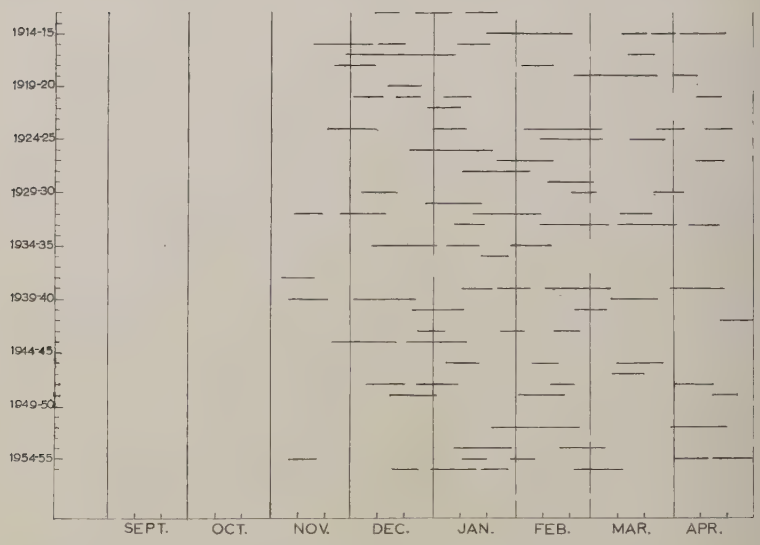

Fig. 2.—Seasonal distribution and length of drought periods.

on 11 January was preceded by 16 days with a total rainfall of 0.01 in. a crop or pasture would probably be suffering from a shortage of moisture before that date, and the total effect of the dry weather would be even more severe than indicated by the actual drought period.

Possible Periodicity of Drought

The data obtained were examined by Mr N. S. Mountier (pers. comm.) using a method suggested by Dr P. Whittle, involving the calculation of correlations of the graph with itself moved back a year, two years, etc. The drought data gave no real indication of periodicity.

Drought and Agricultural Production

Although a considerable amount has been published on the effect of soil moisture deficits on plant growth under controlled laboratory or glasshouse conditions, there is little information on the quantitative effect of drought on the field production of pastures and crops.

In some cases the definition of drought has been based somewhat loosely on the effect on production of some particular crop. For example, Barger and Thom (1949) stated that "the term drought as employed in this study refers to a specific period of time during which the total amount of rainfall recorded at a station is deficient to the extent that, more often than not, the corn yield falls below normal for the county in which the station is situated". Hurlbut (1957) used Ladino clover as a criterion of drought in much the same way as in the present study. That is, he considered that Ladino clover could withdraw 4 in. of water

from the soil before any reduction of yield was noticed. This deficit of 4 in. marked the beginning of a period of drought, which ended when daily rainfall exceeded the water need of a healthy crop. This, in effect, is the definition used in the present study applied to the rooting characteristics of a particular crop.

Parks and Knetsch (1959) in studying corn yields as affected by nitrogen topdressing and drought intensity, obtained a regression equation connecting the three. The use of a maturing crop, such as corn, complicates the picture in that drought will have a different effect at different stages of growth. The corn-growing period of 100 days was, therefore, divided into four periods, and a drought index derived by weighting the number of drought days that occurred in each period. Their results clearly showed the limiting effect that drought can have on fertiliser response. It would be possible, from this type of data, to extend the results of a relatively few seasons' work to other seasons with different climate conditions.

At Winchmore, production figures from several non-irrigated plots on field experiments were available for a number of seasons, and it was considered that the possible relationship between production in a season and the extent of drought in that season should be investigated. Records were available from the 1950-51 to the 1957-58 seasons. Although outside the period of the original investigation, the 1956-57 and 1957-58 seasons were included in order to provide the maximum data. The production records used are comparable only within the particular field experiment: mowing frequency, topdressing, and grazing management all have a marked effect on the measured production. Results were used from lucerne and pasture production trials; and no attempt was made to weight the importance of drought occurring at different times of a season.

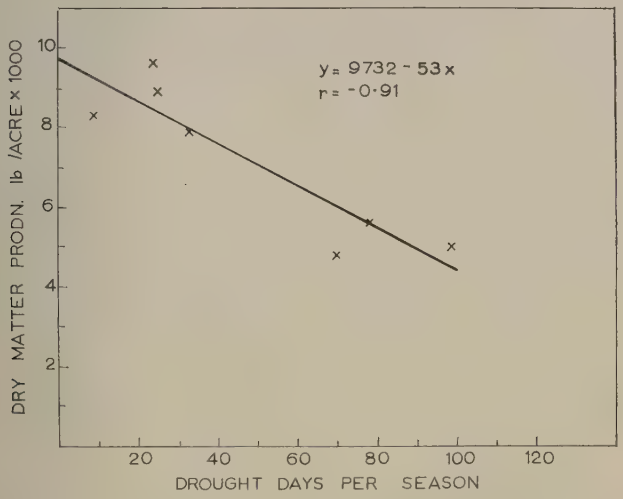

Fig. 3.—Effect of drought days on lucerne production.

Lucerne. Results were available from two trials, on two different areas. The first season's production was omitted in both cases. The results are given in Fig. 3. The regression equation for deriving dry-matter production (lb) from the number of drought days was

$$y = 9732 - 53x \quad . \quad . \quad . \quad (1)$$

where y is the seasonal lucerne production and x the total number of drought days in the season. The correlation coefficient r = —0.91. Lucerne production, as measured under the conditions of the experiment, is, therefore, strongly negatively correlated with the number of drought days in a season. The greatest number of drought days recorded was 107; this corresponds to a lucerne production of 4061 lb. or 41.7% of the production expected in a season completely free from drought.

Pasture. Non-irrigated production records were available for eight seasons from two consecutive Rate of Growth trials; from 1950-51 to 1957-58. Production has been graphed against days of drought in Fig. 4, and the following regression equation derived—

$$y = 6238 - 54x, \; r = -0.92 \quad . \quad . \quad . \quad (2)$$

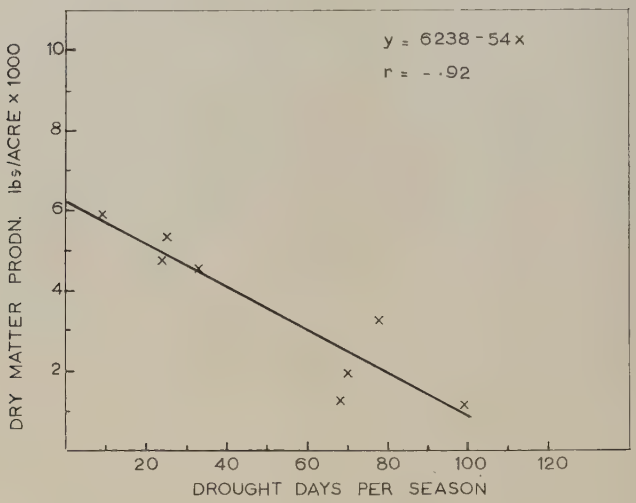

Fig. 4.—Effect of drought days on seasonal pasture production on non-irrigated area.

Where y is seasonal pasture production, and x is the number of days of drought in the season. Again, pasture production (as measured under the conditions of the experiment) is strongly correlated with the number of drought days. The slope of the regression line is almost identical with that obtained for lucerne. Production in an average season of 59 drought days would be about 50% of that in a season with no agricultural drought.

Production records were also available from the non-irrigated area of another pasture production trial, for the seasons 1950-51 to 1956-57. Seasonal pasture production, graphed against the number of drought days, is shown in Fig. 5. The following regression equation was derived

$$y = 6631 - 31x, r = -0.58 \quad . \quad . \quad . \quad (3)$$

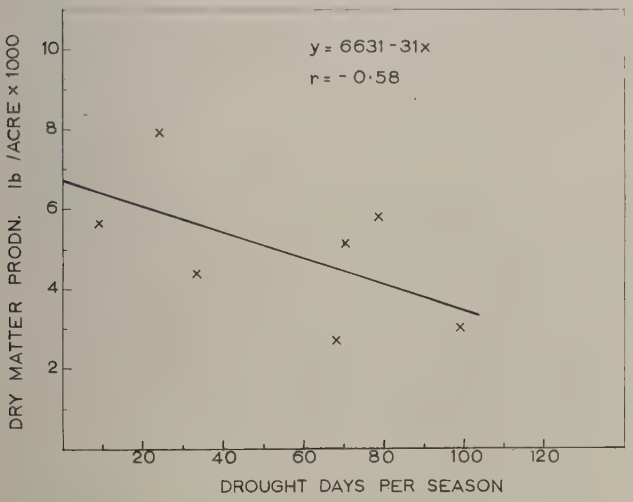

Fig. 5.—Effect of drought days on seasonal pasture production on another non-irrigated area.

Although production is still negatively correlated with the number of drought days, the correlation coefficient is lower, and the regression line has a different slope, from the previous examples.

In considering the relationship between production in a season and the number of days of drought experienced during that season, the possible effect of previous seasons—particularly if dry—should not be ignored. Two or three successive dry seasons would be expected to have a detrimental effect on pasture composition and growth. Under these circumstances, the number of days of drought in a season would have to be weighted to take into consideration the extent of drought in the previous season, or seasons.

Non-irrigated pasture production figures were available from one treatment on a field experiment in which irrigation and no-irrigation were applied in alternate seasons. Production figures were available from four non-irrigated seasons, and these were graphed against the number of drought days in Fig. 6. Any effect due to a dry previous season will be eliminated from these figures. The regression equation was—

$$y = 9528 - 55x \quad . \quad . \quad . \quad (4)$$

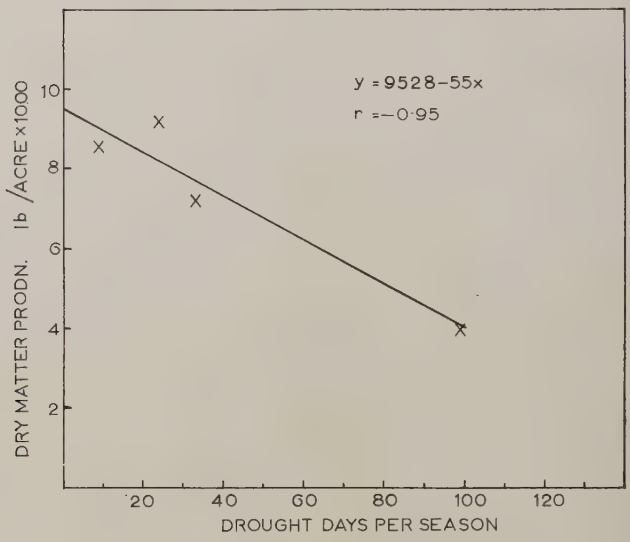

Fig. 6.—Effect of drought days on pasture production for non-irrigated seasons on area where irrigation and non-irrigation were applied in alternate seasons.

The correlation coefficient was —0.95. The slope of this line is almost identical with the lines of equations (1) and (2). It seems likely, therefore, that although previous seasons might be expected to exercise an effect, the slope of lines (1) and (2) was not, over the seasons studied, materially affected by this factor.

Conclusions

The method outlined of defining drought with specific reference to the moisture state of the soil has obvious advantages in agricultural work. The chief disadvantage is the lack of suitable soil moisture measurements, and if one of the methods for estimating these from meteorological data is used, it is important that the suitability and accuracy of the method chosen be established. This is at present being carried out for some selected areas in New Zealand.

A good correlation exists between the total days of drought in a season and the production of lucerne and pasture as measured in a number of field experiments. In an average season of 59 drought days production ranged from approximately 50% to 70% of that in a drought-free season. Production in a drought-free season will be lower than the production obtained under optimum irrigation. The term "drought-free season" means that the soil moisture at no time during the season reached the wilting percentage, but it could be close enough to this to affect production. With optimum irrigation, production would be higher, and the percentage reduction due to drought in an average season correspondingly greater.

ACKNOWLEDGMENTS

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THE EFFECTS OF FREQUENCY AND INTENSITY OF GRAZING ON THE GENOTYPIC STRUCTURE OF A RYEGRASS POPULATION

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Summary

An experiment is described in which changes in the genotypic structure of a short-rotation ryegrass population, as induced by different frequencies and intensities of grazing, were studied.

The plant material was obtained from plants surviving from a sowing of short-rotation ryegrass and red and white clovers which had been subjected to four different grazing systems, and from single-spaced plants grown from the same seed.

From observations made on morphological characters of the plants both in boxes and later in the field, changes in the original population were determined, for the different grazing systems.

In terms of plant means, there was a selection within the original population towards the perennial ryegrass types under frequent and intensive grazing, and towards the Italian ryegrass types under the less intensive and long-spelled grazing systems.

These trends were also shown in the genetic components of the plant variances.

The results are discussed in relation to the rapidity of response to the management systems applied; to the adaptability of the species because of the large number of plants originally used as the genotypic basis of this synthetic strain; and to the species reaction to changing management systems.

The use of simply inherited characters such as fluorescence and awning, for genecological studies in ryegrasses is also discussed.

Introduction

Short-rotation ryegrass (*Lolium perenne* × *L. multiflorum*), a New Zealand-bred variety of hybrid origin (Corkill 1945), has been used extensively in New Zealand since 1945. Management systems applied to pastures containing this variety range from set-stocked continuous grazing to long-spelled lax grazing with hay- and silage-making and conservation of grass *in situ* at any season of the year.

Under this range of management systems, and especially because the plant material from which the variety originated consisted of a number of genotypes ranging from Italian to perennial ryegrass, changes in the genotypic structure of the variety are likely to be induced, even if seeding of the completely inter-fertile population is prevented in the field. Such selection will obviously be dependent on numerous factors. The experiment reported here gives information on the influence of two of these factors, frequency and intensity of grazing.

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No previous work has been carried out on factors influencing natural selection in short-rotation ryegrass although some information has been published on this phenomenon in the ryegrasses as a group. Jenkin (1930), in discussing the origin of two types of early New Zealand perennial ryegrass, which he suggested were originally sown from a common line of ordinary British commercial perennial ryegrass, considered that on the one hand, early Hawke's Bay, Poverty Bay, and some Sandon ryegrass types developed greater vigour and persistency than the original British line because of the influence of continued grazing. On the other hand, South Island conditions favoured the development of rapid-growing, early-seeding and short-lived types which he considered were similar to the poorer sub-types of the ordinary British commercial line. Jenkin further suggested that these types may also have been developed through the inter-crossing of the "commercial" and Italian ryegrasses. The identification and classification of the ecotypes which developed from the possible common source of British seed under New Zealand conditions was carried out by Levy and Davies (1929).

The significance of severity of grazing on the development of ecotypes in perennial ryegrass has been well shown by Gregor and Sansome (1927). Plants were sampled from a population of perennial ryegrass growing in a coastal area in England. They were planted in an experimental field and results obtained showed marked differences in habit of growth in comparison with an erect-growing commercial population. The authors attributed the prostrate habit of growth of the coastal population in its original environment to severe grazing.

From another area which was under grazing for at least 60 years, with severe spring and early summer grazing each year followed by less severe grazing later in the season, two plant types were shown to develop. These were either "prostrate" or "bushy" types whereas the "erect" type commonly found in commercial strains of perennial ryegrass was absent. The presence of the two types and the absence of the other was considered by the authors to be the result of grazing.

Horne (1946) and Gregor and Watson (1954) also showed that pasture management influenced the development of ecotypes, although the latter considered that differences between types were too small to allow the term "ecotype" to be used.

In Holland, Sonneveld (1955) submitted different types and mixtures of types of perennial ryegrass and of timothy to divergent cutting systems for four years, then took rooted tillers from the plots and examined individually the plants growing from them for date of shooting. The early-shooting types were favoured by a management of low frequency, such as cutting for hay after flowering of the grasses, and the late-shooting types by frequent grazing.

In New Zealand, Fejer (1959), from genetic studies on perennial and hybrid ryegrasses, found differences in competitive ability in vegetative and reproductive characters, and suggested that these may lead to changed population structure in later generations.

Natural selection has also been investigated in cocksfoot (Gregor and Sansome 1927; Stapledon 1928; Van Dijk 1955) and in timothy (Gregor and Sansome 1927; Sonneveld 1955; Van Dijk 1955).

It was therefore considered desirable to investigate this phenomenon for the hybrid short-rotation ryegrass, particularly because of its wide genotypic structure and the wide extremes of pasture management applied to it.

Experimental

The investigation was carried out at the Palmerston North station of Grasslands Division, Department of Scientific and Industrial Research, New Zealand.

The plant material investigated was obtained from an experiment to measure the effects of frequency and intensity of grazing on the productivity of a pasture of short-rotation ryegrass and red and white clovers. The details of this experiment and the management procedures adopted have already been reported (Brougham 1959) and only pertinent details will be repeated here. The pasture was sown in late March 1954, and in September 1955 the following four management systems were applied in a randomised block layout with five replications, the plots being 1/20 acre and grazed by sheep.

(1) Grazed when the herbage reached a height of 3–4 in., down to a height of 1 in. (3–1).

(2) Grazed when the herbage reached a height of 6–9 in., down to a height of 1 in. (9–1).

(3) Grazed when the herbage reached a height of 7–8 in., down to a height of 3–4 in. (7–3).

(4) Grazed when the herbage reached a height of 9–12 in., down to a height of 3–4 in. (12–3).

The treatments continued for a period of approximately two years.

On 11-15 July 1957, 120 plants were randomly chosen from surviving populations in each of the four treatments, and a cutting taken from each plant. At the same time, cuttings were also taken from 120 randomly chosen plants from the original seed line, which had been grown as single spaced plants in an adjacent area for a period of over two years under periodical sheep grazing. From each cutting, two single-tiller units of comparable size were hand-separated and planted in boxes $2\frac{1}{2}$ ft x $1\frac{1}{2}$ ft, 60 per box. Each box or replicate contained a plot of six plants from each of the five populations in randomised order, each plant being represented by a pair of single-tiller cuttings placed side by side. Thus the layout consisted of 1200 tillers in 20 replications of 5 treatments, with 6 plants per plot and 2 cuttings per sub-plot.

During the above sampling procedure, a further tiller was taken from each plant cutting, and after folding between filter papers and growing in Hoagland's solution for 7 days, the traces left on the papers by the growing roots were examined for fluorescence under ultra-violet light. A fluorescence test was also performed on seedlings grown from a sample of the seed actually sown in the experiment.

The appearance of the tillers differed quite markedly on placing in the boxes. From the (3–1) treatment they were weak and thin with little sheath material and with leaf blades emerging near the base of the tillers. In treatments (9–1) and (7–3) they were normal and healthy and for treatment (12–3) they were strong and robust with very thick and white sheaths, and leaf blades emerging high above base level. The tillers from the control plants had much dead sheath and leaf blades emerging high above the bases of the tillers.

Because of these differences the tillers in the boxes were treated as favourably as possible by watering frequently with Hoagland's solution and growing undisturbed until 6 August 1957, when they were cut back to $\frac{1}{2}$ in. from soil level. Additional defoliations to this height were carried out on 22 August and 3 September 1957, following undisturbed growth in the intervals.

Following this pre-treatment the plants were again allowed to grow undisturbed until 26 and 27 September when the following measurements were made to determine the treatment effects before transplanting to the field:

1. Green weight per plant.
2. Dry weight per plant.
3. Plant height (length of longest leaf).
4. Number of tillers per plant.
5. Width of longest leaf.

For these measurements only one plant of each pair was measured, except in three of the replications in which both plants were measured to provide estimates of the environmental and genetic fractions of the population variances. Thus comparisons could be made of the effects of treatment both on plant means and on genetic variances, since changes in both of these measures would occur if selection pressure acted to delete or weaken parts of the populations.

Following these measurements, the plants were transplanted to an identical layout in the field at 2-ft spacings. Field treatment consisted of applications of superphosphate and sulphate of ammonia at transplanting and adequate nitrogen for the remainder of the investigation.

In the field, the following measurements were made, on the dates shown:

(1) November-December 1957. Date of ear emergence on all plants. The date of emergence was taken as the day on which the first three ears emerged from the elongated tillers. Short-rotation ryegrass shows a range of emergence time, the earliest types coinciding with the later-emerging plants of perennial ryegrass, and the late-emerging types coinciding with the earlier-emerging plants of Italian ryegrass (L. B. Anderson, Grasslands Division, pers. comm.). It was considered that this character would reflect selection pressure on plant types in the field.

(2) November-December 1957. Awning note for all plants on a scale ranging between 1 (awnless) and 4 (completely awned). This

note was taken because of the heritable nature of this character in ryegrass and its relation to type differences, perennial ryegrass being normally awnless while Italian ryegrass is strongly awned.

(3 10 December 1957. Type Note. The 600 plants were scored on a scale to reflect type, ranging from the dense, narrow-leaved types (score = 1) to the open broad-leaved type (score = 4).

Following grazing to 2 in. on 9 January 1958, further measurements were made, as follows:

(4 17 March 1958. Aftermath heading, on a 0 5 scale. Because there are differences in spread of flowering between perennial and Italian ryegrasses, it was considered that the effects of selection on mean flowering date could be most clearly shown in aftermath heading.

(5 21 March 1958. Note on leaf rust susceptibility on a 0 2 scale (0 = no visible spores , the 600 plants being scored. Perennial ryegrass is much more susceptible to rust than Italian ryegrass.

(6) 19 May 1958. Note on growth and vigour of all plants on a 0–5 scale. The most vigorously growing plants were classified as 5. It was considered that this note would give confirmation of some of the features of the previous notes because of the marked differences in the vigour of strains of ryegrass in the late autumn.

Two additional details of the technique used in the previous experiment (Brougham 1959 are pertinent to the interpretation of the results. Firstly, the pastures were grazed using sheep from other ryegrass areas. During the seeding period, and until the autumn, some seed may have been carried on to the grazing area in the wool of the sheep or in the hooves. Germination of this seed would have been more probable in some treatments than in others because of differences in herbage cover. Secondly, contamination from other natural agencies such as wind-blow, birds, and humans, or from a carry-over of seed or plant material from previous pastures on the experimental area cannot be overlooked.

It is considered that these factors are not serious, especially since any seedlings from such sources would also have been subjected to differential managements for at least part of the experimental period, but the results will be discussed with this limitation in view.

Results

Fluorescence

The results presented in Table 1 show the percentage of fluorescent tillers from tests carried out on 120 randomly selected plants from each of the four grazing treatments, and from the control line, together with a routine fluorescence test on the line of seed sown. Standard errors are also given (from the simple Binomial model). The results indicate that frequent and intensive grazing caused a greater death of fluorecent plants than of non-fluorescent plants, suggesting a shift towards the perennial type hybrid. The sown line of seed gave similar results to the control plants, indicating the validity of the fluorescence tests on clonal material.

TABLE 1. FLUORESCENCE TESTS

Treatment	Percentage Fluorescence and S.E. (no. examined in brackets)
(3–1)	62.5 ± 4.4 (120)
(9–1)	75.8 ± 3.9
(7–3)	63.5 ± 4.4
(12–3)	85.8 ± 3.1
Control	81.7 ± 3.5
Sown Line of Seed	78.8 ± 2.0 (400)
Intensive (3–1), (9–1)	69.2 ± 3.0 (240)
Lax (7–3), (12–3)	75.2 ± 2.8
Frequent (3–1), (7–3)	63.0 ± 3.1
Long Spell (9–1), (12–3)	81.0 ± 2.5

Treatment Differences at Time of Transplanting

The data shown in Table 2 are the means of measurements made on 26 and 27 September 1957, of some of the morphological characters of the cuttings, to determine residual tiller size differences and variability of the experimental material after approximately 11 weeks of uniform treatment.

TABLE 2. MEASUREMENTS OF EXPERIMENTAL MATERIAL AFTER ELEVEN WEEKS OF UNIFORM TREATMENT IN BOXES

Treatment	Plant Height (cm)	Leaf Width (mm × 10)	Tiller Number	Green Weight (g × 100)	Dry Weight (g × 100)
(3–1)	16.12	33.9	28.9	360	45.9
(9–1)	18.11	36.4	32.3	412	52.6
(7–3)	16.05	33.8	26.9	382	48.9
(12–3)	15.86	34.1	28.1	368	47.9
Control	14.57	32.7	29.4	318	40.0
SEs	± 0.37	± 0.6	± 1.9	± 15	± 1.9
Sig. diff. (5%)	1.05	1.8	—	42	5.3

Conclusions:

(i) In height and weight, the means of the control plants were significantly lower than all others.

(ii) In all characters except that of weight, the means for the long-spelled but intensively grazed treatment (9–1) were significantly higher than those for all other treatments. In weight, the (9–1) mean did not differ significantly from that of the (7–3) treatment.

(iii) Differences between the means of the (3–1), (7–3) and (12–3) treatments did not reach significance level.

Table 3 shows the components of variance, cuttings within plants S_c^2 and between plants after removal of cutting variance S_p^2. S_c^2 represents the environmental variance plus the variance introduced

TABLE 3. COMPONENTS OF VARIANCE BEFORE TRANSPLANTING

Treatment	Component	Plant Height (cm)	Leaf Width (mm × 10)	Tiller Number	Green Weight (g × 100)	Dry Weight (g × 100)
(3–1)	S_e^2	9.42	30.5	177.1	18,235	305.3
	S_p^2	0.66	18.9	—	9,443	124.8
(9–1)	S_e^2	10.78	32.4	189.3	17,193	320.2
	S_p^2	0.24	35.0	—	2,721	—
(7–3)	S_e^2	10.31	31.4	169.2	12,919	213.6
	S_p^2	0.61	6.2	—	12,360	167.6
(12–3)	S_e^2	8.33	39.4	275.1	14,901	212.7
	S_p^2	6.20	22.2	—	7,434	105.6
Control	S_e^2	4.19	11.7	166.5	4,669	110.8
	S_p^2	7.78	30.9	97.0	20,417	264.7

S_e^2 is determined with 18 d.f., while (S_e^2 + S_p^2) is determined with 99 d.f.
— denotes zero or negative component.

by the cutting technique itself in growth characters) while S_p^2 represents the genetic variability of the material.

In all characters, the environmental component was of major importance, so that comparison of genetic components was difficult.

In plant weights all pasture treatments, and in plant height all treatments except (12–3), showed reduced plant variances as well as increased means.

In leaf width, the interpretation is confused because the one low plant variance was not associated with a change of mean, while in tiller number the high environmental influence made any conclusion impossible.

The results above in plant weight and height could be interpreted as showing that plant competition in all pasture treatments caused the removal of weaker-growing plants, and in plant height a greater removal of shorter weak plants than of tall robust ones. However, the control tillers were from large many-tillered spaced plants and had sheaths which possibly obstructed their subsequent development. This effect if continuing at the end of 11 weeks of uniform treatment, could itself explain the results obtained.

Treatment Differences in the Field

Table 4 shows the results of the later measurements made in the field.

TABLE 4. FIELD MEASUREMENTS

Treatment	Date of Ear Emergence Nov. 1957	Awning Note Nov./Dec. 1957	Type Note 10 Dec. 1957	Aftermath Heading 17 Mar. 1958	Rust Note 21 Mar. 1958	Growth Note 19 May 1958
(3–1)	26.1	3.41	2.77	2.55	0.77	2.95
(9–1)	25.4	3.70	2.98	2.68	0.55	3.49
(7–3)	26.9	3.62	2.96	2.44	0.84	3.16
(12–3)	28.4	3.79	3.01	2.48	0.62	3.10
Control	27.7	3.55	2.90	2.53	0.68	2.36
S.E.s	± 0.6	±0.07	±0.04	±0.11	±0.05	±0.11
Sig. diff. (5%)	1.6	0.19	0.11	—	0.15	0.32
Intensive (3–1), (9–1)	25.7	3.55	2.87	2.61	0.66	3.22
Lax (7–3), (12–3)	27.6	3.70	2.98	2.46	0.73	3.13
Test of difference	p=.01	p=.04	p=.01	—	—	—
Frequent (3–1), (7–3)	26.5	3.51	2.86	2.49	0.80	3.05
Long Spell (9–1), (12–3)	26.9	3.74	2.99	2.58	0.58	3.30
Test of difference	—	p=.01	p=.001	—	p=.001	p=.04

Conclusions:

(i) As determined by the type and awning notes, a greater percentage of perennial ryegrass type plants were present in the pastures under frequent and intensive management, while a greater percentage of Italian ryegrass type plants were present in the pastures under the lax and long-spelled systems of management.

(ii) In date of ear emergence, there was significantly earlier flowering under intensive grazing than under lax, but there was no significant effect of frequency of grazing.

(iii) In aftermath heading, no significant differences were shown.

(iv) In both rust score and growth note, there were significant differences caused by frequency of grazing but none by intensity of grazing. The frequently grazed plots contained higher percentages of rusted plants, while the long-spelled plots contained higher percentages of autumn-vigorous plants.

Table 5 shows the components of variance for the characters measured in the field.

The table confirms selection processes demonstrated in the data of Table 4.

(i) In date of ear emergence the genetic variance was lowest in the (9–1) treatment, which had the earliest emergence date, showing a loss of later-flowering types under this treatment.

(ii) In awning, the genetic variance was lowest in the laxly grazed treatments, in which a shift of mean towards the Italian type was shown, again confirming the truncation of the population by selection.

TABLE 5. COMPONENTS OF VARIANCE FROM FIELD MEASUREMENTS

Treatment	Component	Date of Ear Emergence Nov. 1957	Awning Note Nov./Dec. 1957	Type Note 10 Dec. 1957	Aftermath Heading 17 Mar. 1958	Rust Note 21 Mar. 1958	Growth Note 19 May 1958
(3–1)	S_e^2	5.5	0.04	0.40	0.55	0.19	1.39
	S_p^2	38.6	0.96		1.18		
(9–1)	S_e^2	5.9	0.05	0.15	0.59	0.47	1.20
	S_p^2	25.6	0.48		1.07		
(7–3)	S_e^2	4.9	0.10	0.25	0.60	0.26	1.15
	S_p^2	31.4	0.44		1.20		
(12–3)	S_e^2	5.7	0.06	0.12	0.44	0.40	1.47
	S_p^2	28.6	0.21		1.55		
Control	S_e^2	2.8	0.05	0.23	0.65	0.37	1.27
	S_p^2	33.2	0.59		1.09		

In Type Note, Rust Note and Growth Note, measurements were made on plant pairs only. Thus S_e^2 cannot be separated, and the values given are estimates of $(S_e^2 + S_p^2)$.

(iii) In those characters for which environmental and genetic variances were not separated, the only important feature was in the rust note, in which the low variances in the frequently grazed treatments (3–1), (7–3) confirmed the finding shown in Table 4 that rust-resistant Italian types had been removed from the population and rust-susceptible perennial types retained.

Indices of heritability (in the broad sense) were computed for the different characters as

$$H = \frac{S_p^2}{S_p^2 + S_e^2} = \frac{\text{genetic variance}}{\text{genetic variance} + \text{environmental variance}}$$

(average values of the components over the 5 treatments being used) and are given below:

Box Data	Plant height	26.4%
	Leaf width	43.7%
	Tiller number	9.0%
	Green weight	43.5%
	Dry weight	36.3%
Field Data	Date of ear emergence	86.4%
	Awning note	89.9%
	Aftermath heading	68.3%

DISCUSSION

The plant material examined in this investigation was derived from a grazing experiment in which no particular precautions were taken to

eliminate possible sources of contamination from other varieties of ryegrass. These sources have already been stated in a previous section of this paper. Consequently, the following discussion must be viewed in relation to the possibility of bias through differential germination of brought-in seed and development of the resulting seedlings in the four treatments. Comparisons between populations in the field treatments are, of course, less open to objection than comparisons between those populations and the control plants, since any plants from brought-in seed would also have been subjected to differential treatments for part or all of the experimental period.

Changes in the original population, using inherited morphological characters as indices, have been determined for the different grazing systems. For most characters measured, the trends are consistent, and show that in terms of plant means there has been a selection of the original plant population towards the perennial type plants in the frequent and intensive grazing systems, and towards the Italian type plants in the less intensive and long-spelled grazing treatments. These trends are also obvious in the genetic components of plant variances.

Many factors can be offered in explanation of the selection, and among the obvious ones are differential death of particular plant types because of their susceptibility to overgrazing (Gregor and Sansome 1927, Branson 1953, Brougham 1960), treading (Edmond 1958), defoliation and base-shading (Mitchell and Coles 1955), and extremes in climatic factors (Lucanus *et al.* 1960). Other equally important factors could be differential susceptibility of the perennial or Italian ryegrass type plants to attacks by insects such as grassgrub (*Costelytra zealandica* (White)) or Argentine stem weevil (*Hyperodes griseus* Hust.).

Italian ryegrass, compared with perennial ryegrass, is more erect in habit of growth and has a less dense crown and fewer, larger tillers. Because of this it is more susceptible to over-grazing and excessive treading than perennial ryegrass. Thus under intensive grazing such as the 3–1 system, selection would be expected to favour the perennial ryegrass type plants. Similarly, in systems of management where long spelling between defoliations is practised, (12–3), inter-species competition for light would act against the perennial ryegrass type plants. It has also been shown by Kelsey (1958) that Italian ryegrass is more susceptible to infestation by Argentine stem weevil than perennial ryegrass. While no direct evidence is available on the causative factor or factors in the selection recorded in this experiment, the effect is probably cumulative with no one factor fully explaining the phenomenon.

The results of this experiment have a number of implications, particularly in view of the rapidity of response to the management systems applied, which occurred in a period of less than two years.

In the first place, they suggest that where the number of plants used as the genotypic basis of synthetic strains is relatively large (Corkill 1956), the resulting strain has wide adaptability, and although selection will operate under different management systems and environments, the resulting pasture may be more productive in the imposed environment than the original line.

Secondly, the results show that management systems applied to pastures have a rapid influence on the phenomenon of natural selection. Under field conditions ecotypes adapted to the induced environment caused by different grazing systems will be produced, in some cases fairly rapidly. It is suggested that this effect is more likely to occur in pastures where the management systems applied are constant, such as on set-stocked sheep pastures or on lax rotationally grazed dairy pastures, where the frequency and intensity of grazing is always the same. However, because management systems applied to pastures in most areas are not as constant as in the grazing experiment reported here, selection towards a particular plant type will probably operate more slowly. It is suggested that where the management of a pasture changes during its life, selection will result in the elimination of a number of the original plant types, and if these changes are radical or numerous the death of a large proportion of the plant types may result. It is probable, as has been previously shown by Levy and Davies (1929) for perennial ryegrass, that a large number of ecotypes have already developed from earlier sowings of the genotypically widely based short-rotation ryegrass in different areas of New Zealand since its introduction in 1945.

One further point is of interest. In the characters measured when the plants were still in the boxes, all of which can be assumed to be controlled by polygenic complexes, and all of which are influenced by environment, the environmental component of variance was of far greater importance than the genetic (Table 3). By contrast, in the field data, although genetic and environmental variances were separated only in characters which are little influenced by environment, it can be seen (Table 5) that the genetic variances are high and the environmental variances low. This difference between the two sets of data shows up clearly in the indices of heritability.

It should be remembered that in the boxes the plants were placed under a common treatment designed to remove environmental differences as far as possible, that the component S_e^2 must include a source of variation of unknown magnitude from the tiller separation technique itself, and that heritabilities of quantitative growth characters were not measured in the field data. Nevertheless, the superiority of the simpler characters, controlled by fewer genes and subject to little environmental influence, in such population studies, is demonstrated.

Finally, the results presented suggest that the fluorescence test used in this experiment is sufficient, as a single index, to show that natural selection occurred and in which direction the genetic shift in the population took place. Although the accepted view is that fluorescence and growth characters are not genetically linked (Justice 1946), Schmidt (1956) and Fejer (1957), have suggested that these characters are, to some degree, genetically linked, and the correlation reported here may support this suggestion. The usefulness of the fluorescence test, as it has been applied by Schmidt, is apparent, as is the use of other characters like awning, which are possibly simply inherited, for genecological work on ryegrasses.

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SOME PHYSIOLOGICAL EFFECTS OF SHADING DAIRY CATTLE

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(*Received for publication, 12 February 1960*)

Summary

This study was carried out in order to determine some of the physiological effects of shading Jersey cows during the New Zealand summer. There was a positive effect of shade in reducing skin temperature and a possible effect on rectal temperature and respiration rate but it is doubtful if this cooling effect is sufficient to justify the use of shade for this purpose under the conditions pertaining to the study.

Introduction

The importance of the provision of shade for cattle in tropical areas is emphasised by studies on the solar radiation heat load (Findlay and Beakley 1954) and its effect on physiological variables (Stewart and Brody 1954; Kibler and Brody 1954). Dairy cattle normally seek shade when subjected to hot, sunny conditions but it is difficult to assess the value of shade since, during the day-time, the animals might have been more comfortable in the shade but they might have spent the time more usefully if grazing.

Shading is one managerial factor the value of which has not been adequately determined in the New Zealand climate. A study was therefore initiated to determine some of the physiological effects of shading New Zealand Jersey cows in the Manawatu district, New Zealand, using rectal temperature, respiration rate, pulse rate and skin temperature as indices of the general physiological status of each animal. The New Zealand climate is not tropical but Garnier (1958) makes the point that in spite of a high rainfall (30 inches per year) and temperate climate, a high percentage of days in the Manawatu have bright sunshine, due mainly to the periodicity of the rainfall and to the prevalence of wind. Also, although the annual variation in mean monthly temperatures is small, there is an extreme temperature range from above 80°F to below freezing point and the mean daily temperature range in the Manawatu is 15.3°F.

A considerable body of work on cattle shades has been published by Californian workers (Ittner *et al.* 1954) and Payne (1955) has reviewed much of the work on practical aspects of shading cattle. Ittner and Kelly (1951) found that air temperatures were of the same order under all types of shades that did not utilise evaporative coolers and they emphasised that the chief function of shade is to reduce the heat load incident to the absorption of radiant energy.

In direct comparisons between the effects of shade and no-shade treatments on dairy and beef cattle, Rhoad (1940), Gaalaas (1945),

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Seath and Miller (1948) and Dowling (1956) found that at high temperatures (i.e. above say 80°F), rectal temperatures and respiration rates are reduced when the cattle are shaded compared with when they are in the sun. No direct measures were made of the solar radiation heat load.

MATERIALS AND METHODS

A reversal type shading trial was conducted during the summer of 1958-59. Eight mature, pedigree Jersey cows of the Massey Agricultural College "Production per Acre Project" herd were chosen at random with the restriction that the highest producers were not considered because of the possibility of upsets to production by the experimental procedure. These cows (described in Table 1) were break-grazed on a predominately short-rotation ryegrass (*Lolium perenne* × *L. multiflorum*) and white clover (*Trifolium repens*) pasture handy to the milking yards where the investigations were made. Turnips (*Brassica rapa* L.) were fed to the group in the paddock after the a.m. milking.

TABLE 1. CHARACTERISTICS OF THE CATTLE USED IN THE SHADING TRIAL

Number	Pair	Age	Weight (lb)	Production (lb)	Days in Milk	Calving Date
18	1	8	979	77	165	28/7/59
33		10	1015	78	173	11/7/59
22	2	7	1076	71	156	19/8/59
74		7	960	77	156	21/8/59
25	3	5	878	109	169	12/9/59
75		6	914	77	170	10/7/59
17	4	3	785	78	149	31/7/59
3		3	846	78	185	7/8/59

Weight: Mean of 2 weighings (7/1/59 and 21/1/59).
Production: lb butterfat for 60 days ending 17/1/59.
Days in milk at 17/1/59.
Calving date estimated from mating records.
Coat colour: Various shades of Jersey fawn-brown.

Four days were chosen between 9 and 15 January 1959 and although there was not continuous bright sunshine on all days, all were fine and warm and there was clear-cut shade.

The cows were paired on age. On the day of reading, two pairs of cows were brought into the yards and one of each pair placed in the shaded open front of an iron-roofed calf shed. The other member of each pair was left in the sun in an adjoining yard. The cows remained penned for one hour before recording was begun. Since, on average, each set of readings (4 cows) took 45 minutes to obtain, the second two pairs of cows were brought in 45 minutes after the first two pairs and were therefore in the yards for one hour before they were dealt with. On days 1 and 4, both groups of four cows were recorded in the order shade—sun—sun—shade, and this order was inverted on days 2 and 3. Treatments were reversed within a pair of cows each succeeding day

so that if a cow was in the shade on day 1, she was in the sun on day 2 and so on. Finally, each cow within a group of four was recorded first on one of the four days.

Rectal temperature was measured with a 4-in., mercury in glass, clinical thermometer (certified correct to within 0.2°F) inserted in the rectum to a constant depth of 3 in. from the anal sphincter. It was found desirable to leave the instrument in position while pulse and respiration rate were being recorded. Respiration rate was measured by counting flank movements (complete respirations) over 30-second intervals. Since interruptions to respiration such as swallowing and eructation were irregular it was thought desirable to establish a rhythm in counting which was continued through such interruptions in order to establish a measurement more indicative of the respiratory status of the animal than of its digestive status. Pulse rate was determined by manual palpation of the ventral coccygeal artery and timed in a similar way to respiration rate. Two repeated readings were made on each cow at each time for each variable and the means used in the analyses.

Skin temperature measurements were made using a copper-constantan thermocouple and a Cambridge portable potentiometer with the reference junction at 32°F in crushed ice in a thermos flask. In accordance with the findings of Patchell (1954), the couple was applied to the skin surface beneath the hairs in the region of the hip bone. The couple, in a small holder, was kept in place and the reading checked over a few seconds to ensure equilibrium. The holder was shaded by the hand when readings were being taken, but only to avoid a direct heating of the couple by the sun. A single assistant was used to work the potentiometer and readings were taken to 0.01°F.

Before reading, each cow was haltered and tied to the yard rails with as little excitement as possible. Air temperature was recorded with each cow by means of a mercury thermometer hung in the shade at the site of operations and wet- and dry-bulb temperature readings were also taken using a sling psychrometer.

One complete set of preliminary readings was taken before the experiment was commenced. This randomised block design (with pairs of cows as blocks) replicated in time (days) was analysed on a time-series, split-plot basis in a similar manner to the example given by Wilm (1945). The first-order interactions were tested by the residual error term and the significances of differences between pair of cow means and treatment means were tested by the interaction between pairs and treatments. The significances of differences between day means were tested by the largest of the interaction mean squares involving days.

Results

Treatment, pair, and day means for each of the four physiological variables, together with the results of the analyses of variance are given in Table 2. Absolute ranges for the four variables were: pulse rate, 69–99 per minute, respiration rate, 26–75 per minute, rectal temperature 101.3°–102.35°F, and skin temperature 90.4°–104.3°F.

The mean air temperature during the trial was 79.1° ± 0.65°F with a range of 71.0° -85.5°F. Mean relative humidity (calculated from the wet- and dry-bulb thermometer readings) was 58.4 ± 0.97% with a range of 48–73%.

TABLE 2. THE EFFECT OF SHADE ON THE PHYSIOLOGICAL VARIABLES

Means

	Pulse	Respiration	Rectal Temperature (°F)	Skin Temperature (°F)
Treatments:				
Shade	84.9	37.4	101.78	93.56
Sun	84.4	42.4	101.95	97.69
Pairs: 1	85.1	34.4	101.93	95.63
2	85.5	39.0	101.69	96.55
3	85.3	46.1	101.89	94.25
4	82.8	40.3	101.95	96.09
Days: 1	87.9	40.4	102.01	96.39
2	86.8	38.4	101.73	96.49
3	85.1	45.0	101.90	94.64
4	78.9	36.0	101.82	95.00

Analyses of Variance

Source	d.f.	Pulse Rate		Respiration Rate		Rectal Temp.		Skin Temp.	
		MS	F	MS	F	MS	F	MS	F
Between treatments	1	1.53	0.03	200.01	4.54	0.340	8.37a	136.54	101.14**
Between Pairs	3	13.11	0.29	187.21	4.25	0.133	3.28	7.89	5.84
Pairs × Treatments	3	44.54	0.69	44.08	0.46	0.041	0.56	1.35	0.42
Between Days	3	129.01	1.99	116.71	1.17	0.133	1.75	7.16	0.76
Days × Treatments	3	12.97	0.20	30.75	0.32	0.045	0.62	7.26	2.28
Days × Pairs	9	46.93	0.73	99.35	1.03	0.076	1.05	9.38	2.94
D × P × T	9	64.71		96.61		0.072		3.19	
Total	31								

a. ($P < 0.10$)
** ($P < 0.01$) Highly significant.

DISCUSSION

Pulse Rate

Pulse rates were relatively uniform during this trial and were high, even in the cows (cows 3, 74, and 33) that had been used in experi-

ments the previous summer and could be expected to be quiet. The readings were taken in the middle hours of the day when values for all four variables would be expected to be the highest in the diurnal pattern (Quartermain 1959). There was a gradation in pulse rate from day 1 to day 4, being highest on day 1, and although this gradation did not show up as a significant difference between days, it could have been an effect of training since the preliminary training period was limited. The days were uniformly hot which could have reduced any variations between days that was not due to a training effect.

Pairing of cows on age only might or might not have reduced the variations between pairs since a cow with a high pulse could have been paired with a cow with a low pulse rate or with another cow with a high rate. In the present study there were no significant differences between pairs of cows. Any possible cooling effects or reduction of heat load due to shading may not have had time to affect pulse rate but no significant treatment effect was seen in this analysis.

Respiration Rate

Respiration rates were also relatively uniform and none of the differences in the analysis were of significant size. In spite of the high temperatures, no really high rates were manifested even in the sun, and it is likely that this group of cows was uniform in heat tolerance.

The no-shade treatment respiration rates were consistently higher than the shade treatment rates on day means and on pair or cow means, but not sufficiently so for the difference to reach significance, possibly because of the small sample of cows involved.

Rectal Temperature

The rectal temperatures of the shaded cows were consistently lower than those of cows in the sun within all pairs and on all days except day 3 (the day of highest shade temperatures). In this case the difference more nearly reached significance ($P < 0.10$) and it is likely that there was a real effect of shade treatment on rectal temperature. Since the main effect of shading was probably to reduce the heat load due to solar radiation and since the heating effect of the radiation would act mainly through the skin and its body-heat balancing mechanisms, it might be expected that rectal temperature would have responded to shade treatment before pulse or respiration rates which would respond to the rise or fall in blood temperature. This assumes that the influence of the blood temperature on the central nervous "heat centre", and thence on cardio-respiratory activities, is more important than direct nervous paths from the skin to the "heat centre", which is possibly true.

It is possible to postulate that shade did have a cooling effect on the animals but it is doubtful whether this effect was great enough to be really beneficial under these New Zealand summer conditions.

Skin Temperature

As mentioned above, the main effect of shading was probably to reduce the effects of solar radiation and therefore the greatest effect of

the treatment would be that on skin temperature. This hypothesis was supported statistically by a highly significant difference between treatment means. This result suggests that care should be taken in the interpretation of skin temperature field data when alternating periods of sun and shade (cloud) are present. In this analysis, both first-order interactions involving days were fairly large (although not significant) suggesting differences between days in the effects of shading. Since the days differed in the amounts of cloud present, this was to be expected.

Quinlan and Riemerschmid (1941—cited by Findlay 1950) found that the mean flank skin temperature (shaved) of a Sussex bull was 98.6°F in the sun and 96.7°F in the shade. The corresponding means in the present study (unshaved) were 97.7°F and 93.6°F respectively.

CONCLUSIONS

There was a possible effect of shade in reducing respiration rate, a more definite effect on rectal temperature and a highly significant effect on skin temperature. The shading presumably reduced the heat load on the cattle incident to solar radiation and thus caused a reduction in skin and body temperatures. It is doubtful whether this cooling effect was enough to justify the economic use of shade under local summer conditions. This is particularly true since the Jersey breed is among the most heat tolerant of the European breeds (Phillips 1953), since temperatures as high as those in the present study only continue for short periods, and since the provision of shade may reduce grazing time.

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NEW RECORDS OF FUNGOUS DISEASES IN NEW ZEALAND 1958-59

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(*Received for publication, 23 February, 1960*)

Summary

The following fungi are recorded from New Zealand for the first time:— *Albugo centaurii* (Hansford) Ciferri et Biga; *Eutypa armeniacae* Hansford et Carter; *Septoria perforans* MacAlpine; *S. scabiosicola* Desm.; *Piricularia grisea* (Cke.) Sacc.; *Alternaria porri* (Ellis) Ciferri; *Heterosporium allii* Ellis et Martin; and *Cercospora platensis* Speg.

Additional host records include:— *Albugo tragopogonis* Pers. ex S. F. Gray on *Gerbera jamesonii* Bolus; Erysiphe *cichoracearum* DC on *Solanum tuberosum* L. (potato), and on *Penstemon hartwigii; E. polygoni* DC on *Ranunculus asiaticus* L.; *Sphaerotheca fuliginea* (Schlecht.) Poll on *Calendula officinalis* L.; *Pleospora herbarum* (Pers. ex Fr.) Rabenh. on *Lactuca sativa* L. (lettuce), and on *Lycopersicon esculentum* Mill. (tomato); *Gibberella saubinetii* Mont. on *Lycopersicon esculentum* Mill.; *Corticium rolfsii* (Sacc.) Curzi (syn. *Sclerotium rolfsii* Sacc.) on bulbs of *Allium cepa* L., *Iris xiphium* L., and *Nerium filifolia* Baker, and on *Lycopersicon esculentum* Mill.; *Fusarium avenaceum* (Fr.) Sacc. on *Matthiola incana* R.Br. The basidial form of *Sclerotium rolfsii* was present on bulbs of *Iris xiphium* and was typical of *Corticium rolfsii* (Sacc.) Curzi.

The following records are based for the most part on material identified and collected during the past twelve months. In all cases specimens have been placed in the herbarium, Plant Diseases Division, Auckland; the herbarium number is quoted in brackets after citation of the collection.

1. *Albugo centaurii* (Hansford) Ciferri et Biga, Sydowia *9:* 355; 1955. Syn. *Cystopus centauri* Hansford, Proc. Linn. Soc. N.S.W. *79:* 97; 1954.

   on *Centaurium minus* Moensch, Auckland, Henderson, S. D. Brook, Dec. 1958 (18555).

   on *Orphium frutescens* E. Meyer, Auckland, Glendowie, H. M. Mouat, Dec. 1955 (18597); Taranaki, New Plymouth, T. Mayo, Feb. 1959 (18859).

   Conidial sori scattered on both upper and lower surfaces of leaves and stems, cream or white, pulvinate, erumpent when mature, up to 1 mm diam., often surrounded with ruptured epidermis. Mycelium branched, hyaline 3-5 μ diam.; conidiophores compacted on sori, subclavate, 24–35 × 12.5–16 μ. Conidia acrogenous, in chains joined by colourless connectives, globose, sometimes cuboid with mutual pressure, 16–22 × 15–21 μ hyaline, showing a distinct annular thickening 1–1.5 μ thick. Oogonia formed in leaf tissue beneath old conidial sori, 65–90 μ, thin walled, with a single oospore; antheridia thin walled oval, 25–35 μ diam.; mature oospores chestnut brown, globose 48–55 μ epispore 4–6 μ thick, closely reticulate with thickened branched ridges.

Hansford (1954) describes this species from infected *Centaurium spicatum* (L) Druce from Kosciusko, New South Wales, Australia. He states that the Australian species differs from *Albugo swertiae* Berl. et Kom. in that oospores and conidia are larger. Saccardo (1912) gives measurements of conidia as 12–16 × 11–13 μ and oospores as 45–50 μ. The New Zealand material agrees with the Australian descriptions; oospores were found only in the collection of *Centaurium minus*.

2. *Eutypa armeniacae* Hansford et Carter, Aust. J. Bot. *5:* 22; 1957.
on dead wood of *Prunus armeniaca* L. (apricot), Canterbury, Heathcote, J. M. Dingley, May 1958 (18852; 19099).

Perithecia on decorticated wood, immersed in a modified substrate. Stroma not clearly defined, effuse, sometimes more or less pulvinate, formed of lightly pigmented mycelium in among the superficial layers of phloem and xylem. Perithecia brown-black, irregularly arranged in a single layer, obpyriform 400–500 μ diam., with distinct papillate ostiole, neck 150–200 μ long, lined with periphyses. Ostiole not sulcate, simple, sometimes umbilicate. Perithecial wall with 2 distinct layers: an outer pseudoparenchymatous layer 30 μ thick, cells 7–10 μ diam. with pigmented thin walls; inner layer 20 μ thick, prosenchymatous, mycelium with thin hyaline walls, diffluent in mature perithecia. Asci clavate, sometimes elliptical, stalked, with thickened truncated apex, 40–80 × 3–4 μ, fertile part 28–50 μ long, 8 spored, biseriate; paraphyses absent. Spores unicellular, cylindrical, allantoid, lightly pigmented, 5.5–9 × 1.5–2 μ.

Pycnidia semi-immersed in immature stroma, labyrinthiform; conidia filiform, 1 celled, 23–32 × 1–1.5 μ, filiform, cylindrical, often arcuate.

This fungus has already been recorded from New Zealand (Dingley 1960) but no description of the organism was given.

In Australia this fungus has been shown to be associated with die-back of apricot trees (Carter, 1957). In Heathcote it is associated with a similar disease; pathogenicity has been demonstrated with cultures from New Zealand material. Collections were examined by Carter who stated that they were identical with the Australian organism. In New Zealand this organism has been found only on apricot, but in Australia Carter (1958) reported that perithecia has been found on *Prunus amygdalus* Batsch, *Tamarix* sp., *Vitis vinifera* L. and ascospores from these perithecia readily infected apricot wood. When Carter recorded the association of this fungus with apricot die-back he noted that it was the first record of a pathogen in *Eutypa*. It should be noted, however, that Barthelet (1938) records *E. lata* (Pers.) Tul. var. *ribis* as a pathogen on black currants (*Ribes nigrum* L.); he describes and illustrates a species similar to *E. armeniacae* causing more or less identical symptoms. Moreau and Moreau (1951) suggested that *E. acharii* (Fr.) Tul. was pathogenic on *Acer pseudo-platanus* L. Davidson and Lorenz (1937) described a species in the closely related genus *Eutypella* (*E. parasitica* Davidson et Lorenz) as a pathogen on *Acer saccharum* Marshall and on *A. rubrum* L.

3. *Septoria perforans* MacAlpine, Proc. Linn. Soc. N.S.W. *28:* 100; 1903.

on *Cryptostemma calendulacea* R.Br., Auckland, Mt. Albert, J.M.D., May 1958 (18509).

Lesions numerous, pale gray, angular 0.5–1 cm diam., often confluent with one another, sometimes poorly defined and visible only from the upper surface of leaf. Pycnidia numerous, scattered, semi-immersed in leaf tissue, brown, globose, 75–100 μ diam., thin walled with distinct ostiole. Pycnospores hyaline, filiform, often arcuate, 1–3 transverse septa, 22.5 $\times$ 2–3.5 μ.

S. perforans was first described from Australia; it is recorded from South Africa (Doidge 1950). Morphologically this species is similar to *S. lactucae* Pass.; unfortunately no cross inoculations have been carried out.

4. *Septoria scabiosicola* Desm., Ann. Sci. Nat., *20:* 96; 1835.

on *Scabiosa atropurpurea* L., Auckland, Mt. Albert, J.M.D., Sept. 1958 (18500).

Lesions numerous, circular up to 0.5 mm diam., often fusing together, ash grey, surrounded by brown margins, lesions often containing only a single pycnidium. Pycnidia few, globose, dark brown, 130–150 μ, obpyriform with an erumpent ostiole; thin walled, 5 μ thick, often only 1 cell wide, cell walls pigmented. Conidia hyaline, filiform, 3–4 septate, 32–62 $\times$ 1–1.5 μ.

Specimens were collected from heavily infected plants and the fungus was causing a considerable amount of defoliation. Pycnidia present in this New Zealand collection agree with the description given by Grove (1935) for the fungus on leaves of *Scabiosa succisa.*

5. *Piricularia grisea* (Cke.) Sacc., Michelia *2:* 148; 1880.

on *Digitaria sanguinalis* (L.) Scop., Auckland, Henderson, P. J. Brook, Jan. 1959 (18871).

Lesions ochraceous with purplish margins, usually on leaves, 3–5 mm diam.; conidiophores formed in clusters, penetrating through stoma on both upper and lower surfaces of leaves, pigmented, unbranched, transversely septate, with a swollen base, 50–100 $\times$ 3–4 μ. Conidia budded off singly from apex of conidiophores, successive growing points developing on alternate sides of previously terminal conidia. Conidia pigmented, 2 septate, obpyriform, sometimes oval, end cell often attenuated, base broad and truncated, 19–28 $\times$ 8–10 μ.

Up to the present in New Zealand *Piricularia grisea* has been found only on crab grass. Sprague (1950) stated that this species was not readily distinguishable from *P. oryzae* but inoculation experiments have shown the latter to be host specific.

6. *Alternaria porri* (Ellis) Ciferri, J. Puerto Rico Dep. Agric. *14:* 30; 1930.

Macrosporium porri Ellis, Grevillea *8,* 12; 1879.
Alternaria alli Nola, Phytopathology, *17;* 118, 1927.

on *Allium porrum* L., Auckland, Remuera, J.M.D., March 1959 (18860).

Lesions lens-shaped, 1–4 cm long, 1 cm wide, grey with vinaceous brown margins, sunken in the centre, sometimes retting, dark coloured due to brown conidiophores and conidia. Conidiophores formed singly, brown with 1–2 transverse septa, up to 35 μ long. Conidia formed singly, obclavate, olivaceous brown, 110–130 $\times$ 16–20 μ with 9–12 transverse septa, 1–2 longitudinal septa, beak single, 20–45 μ long, tapering.

In this collection the fungus produces a number of lesions on young leek plants in early autumn. The fungus is common in warm, temperate countries (Commonwealth Myc. Inst. Distribution Map 350) where it is reported as causing a purple blotch on leaves of onions and leeks.

7. *Heterosporium allii* Ellis et Martin, J. Mycol. *1:* 100; 1885.
H. ornithogali Klotsch var. *allii porri* Sacc. et Briand, Rev. Mycol. Toulouse *8;* 23; 1886.

H. allii var. *alli porri* (Sacc. et Briand) Sacc., Syll. Fung. *4:* 480; 1886.

on leaves of *Allium porrum* L., Christchurch, J.M.D., Sept. 1959 (19089).

Lesions elliptical, light coloured, causing leaves to die from the tip downwards. Conidiophores borne singly, sometimes in clusters, from a dark prosenchymatous knot, 120–200 $\times$ 6–8 μ, septate, greyish brown, forming a dense mass on margins of lesions. Conidia terminal, formed from successive new growing points, new conidia developing from one side of the previous terminal conidia, giving conidiophores a twisted appearance. Conidia 1–3 transverse septa, cylindrical or obpyriform, sometimes constricted at septa, 17–32 $\times$ 8–11.5 μ, olivaceous brown, finely echinulate.

New Zealand material agrees with the description given by Moore (1946). Moore reserved this name for the organism responsible for leaf blotch on leeks, shallots (*Allium ascalonimum* L.), chives (*A. schoenoprasum* L.) and garlic (*A. sativum* L.). He stated that the *Heterosporium* sp. on onion (*Allium cepa* L.) had consistently larger conidia and should be regarded as a distinct variety of *Heterosporium allii.* In New Zealand this fungus has been collected only on leeks.

8. *Cercospora platensis* Spegazzini, An. Soc. cient. argent. *10:* 38; 1880.
on leaves of *Muehlenbeckia australis* (Forst. f.) Meissn., Canterbury, Banks Pen., Prices Bush, J.M.D., March 1959 (18876); Marlborough, near Kaikoura J.M.D. March 1959 (18886).

Lesions light yellowish, 1–2 cm diam., often forming an abscission layer within healthy tissue shedding the diseased part. Conidiophores formed only on under surface of leaves, giving a sooty appearance; conidiophores borne in clusters on minute brown pseudoparenchymatous stroma 20–35 μ diam., brown, up to 40 μ

long, 5 μ diam., sparsely septate but unbranched; conidia obclavate, cylindical, sometimes falcate, lightly pigmented, 1–7 (usually 3–5) transverse septa, 32–85 $\times$ 5–6.5 μ.

New Zealand material agrees with the description given by Chupp (1954). It is not uncommon in the coastal region of north Canterbury. The infected leaves have a characteristic tattered appearance due to shedding of the diseased portions of leaves.

ADDITIONAL HOST RECORDS

9. *Albgo tragopogonis* Pers. ex S. F. Gray, "A Natural Arrangement of British Plants" *2:* 540; 1821.

on *Gerbera jamesonii* Bolus, Auckland, Northcote, ?, Oct. 1959 (19104).

Specimens were brought into the laboratory by a grower. The leaves were heavily infected. He stated that only some varieties were infected. Pustules were mostly on the under surfaces of the leaves; a few sori were present on the upper surface of leaves and on the midrib; oogonia were formed beneath the old conidial pustules.

10. *Erysiphe cichoracearum* DC in Lamarck and De Candolle, Flore Francaise *2:* 274; 1805.

on *Solanum tuberosum* L., Canterbury, Cheviot, J.M.D., March 1959 (18884).

on *Penstemon hartwigii* x Auckland, Remuera, J.M.D., Oct. 1959 (19087).

In both collections the oidium stage only was present.

11. *Erysiphe polygoni* DC in Lamarck and de Candolle, Flore Francaise *2:* 273; 1805.

on *Ranunculus asiaticus* L., Auckland, A. Webb, Sept. 1958 (19088).

The oidium stage only was present in this collection.

12. *Sphaerotheca fuliginea* (Schlecht.) Poll, Atti. Ist. Bot. Univ. Pavia, ser. 2, *9:* 158; 1911.

on *Calendula officinalis* L., Auckland, Mt. Albert, J.M.D., April 1959 (18854).

The oidium stage only was present in this collection.

13. *Pleospora herbarum* (Pers ex Fr.) Rabenh., In Klotzsch Herbarium Vivum Mycologicum 2nd ed. p. 547; 1857.

on *Lactuca sativa* L., Auckland, Avondale, P. J. Brook, Sept. 1958 (18525).

on *Lycopersicon esculentum* Mill., Auckland, Mangere, F. J. Newhook, July 1959 (19006).

A strain of *Pleospora herbarum* was first found to be pathogenic to lettuce by Ogilvie and Mulligan (1931) in England; later it was recorded from Italy, United States, and Argentine. Padhi and

Snyder (1954) stated that this strain was host specific to lettuce and proposed the combination *Pleospora herbarum* var. *lactucum*.

Although no pathogenicity tests were carried out, from the literature (Ramsey 1953) it would appear that the form on *Lycopersicon esculentum* is also specific. Ramsey related this form to *Pleospora lycopersici* Marchal et Marchal, and stated that it was morphologically identical with *P. herbarum*. In these local tomato specimens the fungus caused a watery stem-end rot of the fruit; conidia were first formed but later perithecia developed on the rotten fruit. Symptoms were distinctly different from those obtained when similar fungi (e.g. *Alternaria tenuis* Auct.) attacked damaged tissue.

14. *Gibberella saubinetii* (Durieu et Montagne) Sacc., Michelia *1:* 513; 1879.

Gibbera saubinetii Mont., Syll. Crypt. 252; 1856.

Sphaeria saubinetii (Durieu et Montagne), Flore d'Algerie Paris, *1:* 447; 1876.

on *Lycopersicon esculentum* Mill., Auckland, Mt. Eden, F. J. Newhook, July 1959 (19005).

This fungus has previously been recorded in New Zealand as *Gibberella pulicaris* var. *minor* Wr. on *Humulus lupulus* L. (hops) where it is responsible for a stem canker. In these collections it was present on green but fully grown tomatoes where it appeared to be responsible for a stem-end rot. When infected fruits were cut the flesh was a purplish red colour; some fruits produced mature perithecia. A similar fruit rot was reported from U.S.A. by Crozier and Boothroyd (1959) who stated that the fungus resembled *Gibberella zeae* (Schw.) Petch.

Unfortunately throughout mycological literature there has been great confusion in the interpretation of *G. saubinetii*. Wollenweber (1931) regarded this species as the one occurring on Gramineae, i.e. the one responsible for foot rot and scab of wheat; Petch (1936) stated that whatever view was taken of Montagne's species it cannot be confused with *G. zeae* (Schw.) Petch; Petch then correlated *G. saubinetii* with *G. cyanogena* Desm., a species with large tuberculate perithecia, large spores but with a poorly developed stroma. Although type material of *G. saubinetii* in both the herbarium at Kew and in the Montagne herbarium at Paris is immature, perithecia are sufficiently characteristic to suggest it is a separate species. Spore measurements given by Montagne agree with mature collections found in New Zealand. Re-examination of collections cited by Wollenweber as *G. pulicaris* var. *minor* show his interpretation of this species to be similar to *G. saubinetii* Mont.

15. *Corticium rolfsii* (Sacc.) Curzi, Boll. R. Staz Pat. veg. Roma n.s. *11:* 365; 1932.

syn. *Pellicularia rolfsii* (Sacc.) West., Phytopathology *37:* 69; 1947.

on *Allium cepa* L., Auckland, Otara, R. McNabb, June 1954 (19135).

on *Iris xiphium* L., Wellington, Otaki, F. W. Flint, May 1954 (13146).

on *Lycopersicon esculentum* Mill., Auckland, Avondale, B. Colman, Jan. 1960 (19149).

on *Nerium filifolia* Baker, Auckland, ?, April 1959 (18912).

This fungus has formally been recorded in New Zealand (Brien and Dingley, 1951) only as the sclerotial stage as *Sclerotium rolfsii* Sacc. Examination of the fungus infecting the iris bulbs showed not only the typical brown sclerotia, but small floccose ochraceous patches among the mycelial strands. Microscopic examination proved these patches to be a hymenial layer of compacted basidia. This is the first recording of the basidial stage of this fungus in New Zealand.

16. *Fusarium avenaceum* (Fr.) Sacc., Syll. Fung. *4:* 713; 1886.

on *Matthiola incana* R.Br., Otago, East Taieri, G. Poole, June 1959 (18931).

The *Fusarium* was associated with a basal stem rot, causing wilt of the plants; sporodochia of the fungus were present on the basal canker.

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SOME METABOLIC ASPECTS OF THE PASTURE/ANIMAL ASSOCIATION

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Summary

Experiments are reported in which the resting-lactating heat production of dairy cows was determined by indirect closed-circuit calorimetry and the results indicate that the grazing of highly improved ryegrass-clover pastures markedly increases the rate of thermogenesis. Compared with cows grazed on less improved swards, this excess heat production was of the order of 22–24%.

It is suggested that the large thermodynamic costs incurred by cows grazed on such fodder is the principal factor contributing to the low energetic efficiency characteristic of dairy-cow production in New Zealand. It is shown that even when adequate allowance is made for the additional energy expenditure associated with grazing activity, the measured feed consumption of 100 cows grazed on improved New Zealand pastures is sufficient to maintain 122 cows at the same productive level if fed wholly or largely on compounded rations in accordance with established feeding standards.

It is postulated that disposal of the excess nitrogenous compounds arising from the consumption of high-protein pasture causes the large heat increment of the energy available to the cows from their pasture diet, thus reducing their feed conversion efficiency. The physiological effects of energy-deficiency, and its relationship to metabolic disorders of grazing animals, are briefly discussed, also the feasibility of rectifying the energy : protein imbalance by breeding pasture species of lower protein content, or by alternative methods of feeding and pasture management.

These experiments showed that the heat production of lactating cows is proportional to their heart rates and could be estimated with reasonable accuracy by means of the expression: $M = 200P$, where "M" is the total heat production in kilocalories and "P" is the observed recumbent heart rate. It is contended that the higher rate of metabolism was not merely an associative effect of increased milk output from the superior pastures since the mean difference in milk yield from the improved and less improved pastures (i.e. 4.3%) was not significant. Other factors, including mineral deficiencies, which might contribute to the heightened metabolic rate and reduced energetic efficiency are also discussed.

Introduction

Although dairy cows in this Dominion are uniquely dependent upon pasture or its products as their sole source of sustenance, our physiological concepts and our approach to many nutritional problems affecting these animals are still based upon conventional knowledge accumulated in overseas countries where cows are fed upon a variety of feedstuffs among which pasture may be only a minor component or may even not be fed at all. It is generally recognised that this fact could account for quite important differences in the nutritional physiology of ruminants maintained in these two distinctly different environments but specific study of the resultant problems has been astonishingly neglected.

One such problem is posed by the highly improved pastures which, largely through the efforts of our grassland specialists, have become a distinguishing feature of animal production in New Zealand. Pasture improvement measures have frequently been criticised by veterinarians and others who base their objections upon the fact that the high protein content characteristic of such pastures, the narrow range of plant species that comprise these swards, and the fluctuations that occur in certain pasture constituents, appear to provoke metabolic disorders in sheep and cattle. On the basis of existing biochemical knowledge these seem to be quite valid criticisms, although many agricultural advisers and some grassland workers are disposed to contest this view and, indeed, have claimed that improved high-production pastures will unfailingly meet all the nutritional requirements of the grazing ruminant and enable it to produce and reproduce at a satisfactory level with high efficiency and without physical handicap.

The situation in this country is somewhat unusual since it is the pasture ecologists who, in effect, prescribe the diet on which our animals are fed, hence they tacitly assume the mantle of the nutritionist. Therefore, it is of interest to note an increasing willingness on their part to accept some of the responsibility for such nutritional disabilities as may fairly be attributed to pasture 'improvement', although they not unnaturally make some minor reservations (Melville 1953; Johns 1956; Sears 1959).

There has, however, been a conspicuous lack of concrete evidence definitely implicating pasture improvement in the genesis of the various metabolic syndromes. Obviously, it would be of value to compare the physiological reactions of animals grazed on improved pasture with those fed on less-improved or more 'natural' herbage. Such a comparison can best be accomplished by examining the *energetic efficiency* of animals maintained under these two respective types of feeding and such a study will constitute our present purpose.

The aim of this paper, therefore, is to review the available data, to extend them with evidence derived from animal calorimetric measurements, and to attempt an assessment of the physiological effects arising from imbalance among the fodder constituents which influence feed utilisation by the grazing animal.

THE EFFICIENCY COMPLEX

The efficiency with which farm livestock convert their food into useful products, such as milk, meat, or wool, unquestionably provides the most reliable indication of both the adequacy and the nutritional suitability of their diet. Insofar as dairy cows are concerned, it is evident that the actual level of milk production is not, of itself, a sufficient measure of efficiency but must be considered in relation to the amount of consumed food necessary to produce it. Milk yields are not invariably proportional to the feed intake since the conversion of feed to product is influenced by factors such as breed, quantity and quality of feed available, climate, the type of husbandry, and physical characteristics of the animals.

In the case of a dairy cow, it can be assumed that the food eaten is used solely for three purposes, namely, (a) maintenance, (b) milk production, and (c) growth, but the proportions of the total food which the cow is able to allot to each of these uses varies among individuals, so that different levels of performance are observed on the same nutrient intake. Therefore, in assessing dairy-cow efficiency it is necessary to partition the total food between these three functions. Obviously, there can be no direct means of doing so but a mathematical method, which has gained wide recognition among animal physiologists, has been devised and gives reliable and reproducible results.

The basic equation employed in this partitioning process consists of three terms:

$$\text{t.d.n.} = \text{b (f.c.m.)} + \text{c(l.w.}^{0.73}\text{)} + \text{d(l.w.c.)}$$

where "t.d.n." is the feed intake per day expressed as Total Digestible Nutrients, "f.c.m." is the daily yield, in pounds, of fat-corrected-milk, "l.w.$^{0.73}$" is the live weight of the animal reduced by the parameter 0.73 power of live weight (which represents the "physiologic unit" of weight of all mammals), "l.w.c." is the daily weight change, positive or negative, and the constants "b", "c" and "d" are determined for the particular data, usually by application of the method of least squares.

Much information relating to the effect of varying nutritional planes upon the apportionment of consumed nutrients between these three functions has been accumulated by workers at several centres, principally in Europe and the U.S., where, in the main, it has been based upon animals stall-fed, in which case their feed intakes are readily measurable. But during recent years workers at the Ruakura Animal Research Station have succeeded in developing a technique which enables the food consumed by free-grazing cows to be estimated with a high degree of accurancy (Lancaster 1953, 1954). Using these data they have derived the same conventional type of equation for partitioning the daily food consumption between the three purposes mentioned. Thus, the physiological efficiency of pasture-grazed lactating cows can be defined in the same terms as those employed overseas in respect of stall-fed cows.

Efficiency of New Zealand Pastured Cows

There has been considerable variation in the equations published by Ruakura year by year (N.Z. Dept. Agr. 1951, 1956, 1957) but one which summarised the study of a total of 217 cows over a period of 6 years, and involved a wide variety of climatic, grazing, and management conditions, probably represents the performances of New Zealand pasture-fed cows with as high a degree of accuracy as is attainable in the circumstances (Wallace 1956).

This study showed that on the average these cows, of mixed Jersey and Friesian breeds of very diverse live weights, milk yields and feed intakes, consumed 22.30 lb of t.d.n. per day, produced 24.5 lb daily of fat-corrected-milk, and gained weight at the rate of 0.64 lb daily.

The mean liveweight of the 217 cows was 849 lb. The derived equation is:

$$\text{t.d.n.} = 0.35\ (\text{f.c.m.}) + 0.08\ (\text{l.w.}^{0.73}) + 3\ (\text{l.w.c.})$$

If the total daily feed intake of 22.30 lb t.d.n. be apportioned in accordance with the above equation it will be seen that the feed cost is 8.9 lb t.d.n. for milk production, 11.4 lb for maintenance, and 2.0 lb for live-weight gain.

These feed costs can most conveniently be compared with overseas estimates by assuming the case of a dairy cow of 1000 lb body weight and, since British feeding standards are commonly based upon "starch equivalent" units instead of total digestible nutrients, conversion to those units yields the following comparison.

TABLE 1.

Source	Milk Production per lb F.C.M. (lb S.E.)	Increase	Maintenance of 1000-lb Cow (lb S.E.)	Increase
British feeding standard*	0.26	—	6.0	—
Ruakura	0.32	23%	11.4	90%

* Brit. Min. Agric. Rations for Livestock, Bull. 48.

It will be seen that the feed cost of milk production is slightly higher for New Zealand pastured cows than for British rationed animals but this is not unexpected as numerous studies, reviewed by Leitch and Godden (1941) have convincingly established that a stall-fed cow produces a given yield of milk more efficiently than a grazing cow because of the high protein content and relatively low energy value of good pasture. But the *cost of maintenance* of the pasture-fed cow producing the same amount of milk is nearly double that found sufficient for a cow predominantly stall-fed and rationed in accordance with approved British feeding standards (or with European and U.S. standards). This very substantial difference in the maintenance cost obviously raises important questions of physiological interest.

It is of course apparent that a pasture-grazed cow will expend more energy in unproductive purposes than will one stall fed because it may walk several miles daily in the process of grazing and foraging and in visits to the milking shed. It may also expend more energy in maintaining body temperature in cold conditions than would a housed cow. In the animal's economy these demands take precedence over the use of energy for conversion into milk or live-weight gain and only nutrients in excess of basic requirements are available for these useful productive purposes. But apart from the feed cost of grazing activities there is no apparent physiological reason why a grazed cow should require more feed than one stall-fed.

The Energy Cost of Grazing

In reporting the Ruakura results from time to time, officers of that Station have suggested that the energy of foraging and grazing is the major factor responsible for the much greater maintenance requirement of pasture-fed animals. However, there is no available evidence to indicate that the energy expenditure associated with grazing activity should be the major cause of this high cost of maintenance. Several estimates have been made by various workers concerning this activity increment but none of them result in a maintenance food requirement approaching double that incurred by a stationary cow.

For example, the scale of feeding recommended by the British Ministry of Agriculture implies that an extra 15% of nutrients should be adequate to support grazing activity on average quality pasture. while Sjollema (1950), in the Netherlands, concluded from investigations extending over 11 years, that the daily energy requirement of grazing cows amounts to 30% above those stall-fed. This may be a generous estimate since American work by Brody and Hall (1950) relating to the caloric cost of standing and walking, when combined with grazing behaviour studies in New Zealand, suggests that an allowance close to 20% additional energy should adequately cover requirements (Hickey 1953).

Admittedly, there may be many instances where the distance walked per day by a grazing cow exceeds that deduced from observational studies, as it could be influenced by the state and quality of the pasture, by the prevailing weather conditions, and perhaps by other factors. Furthermore, such theoretical assessments of caloric expenditure computed under experimental conditions are apt to prove unreliable under practical conditions, and it may therefore be prudent for present purposes to accept the higher Netherlands estimate of 30%. By analogy with the sheep this appears to be a reasonable figure as Blaxter (1948) has shown that the activity increment of the sheep is about 33% of its basal expenditure and there is little doubt that sheep graze more extensively than do dairy cows, particularly when the latter are gestating or lactating, as under these conditions cows appear instinctively to restrict their energy expenditure.

But the estimated figure of 30% is a long way short of the postulated 90%, and it is apparent that quite large metabolic losses are in some manner incurred by dairy cows freely grazing improved pasture. If it can be shown that this disturbance of biological function is related to, or arises from, botanical and chemical characteristics of the improved swards, a challenge is presented to plant breeders and pasture ecologists to take corrective measures if these be possible. Some authorities doubt the feasibility of doing so, while not denying the need, but the question has not yet received the critical attention it warrants.

The economic implications for the dairying industry are of equal importance to those having a physiological basis. For example, if these metabolic losses could in some manner be avoided, while still allowing a 30% increment in the maintenance feed component to cover grazing activity, 122 cows could be maintained on the feed intakes now

required by 100 cows at Ruakura, with of course an additional 22% milk production.

No satisfactory explanation has been offered to account for this considerable loss of efficiency in the conversion of feed energy into useful product but it would clearly seem that cows in the New Zealand environment fed on highly improved pasture waste an undue proportion of their feed by spendthrift oxidation of nutrients they are unable to direct into useful channels of metabolism. There are two forms of energy to be considered: one which takes the form of work, including milk synthesis and growth, and is called "dynamic" energy, and the other which takes the form of heat and is known as "thermic" energy.

It should be appreciated that the animal body possesses no power of converting heat into work or other form of useful energy. Whatever part of the feed has taken the form of heat has lost the property which the digested nutrients originally possessed of being applied to various purposes, and has passed completely beyond the influence of the body. Heat, once it is manifested, can act only as such and, except under conditions of low environmental temperature, it finds no further useful application in the body but requires to be dissipated by the animal's heat-regulatory mechanisms.

It would appear obvious, therefore, that the thermogenic waste apparently characteristic of New Zealand pastured cows arises from factors in the pasture/animal association capable of profoundly disturbing the normal metabolic processes of these animals when they are freely grazed on "improved" pastures.

THE METABOLISM OF PASTURE-GRAZED COWS

If it be true that the abnormally high feed cost of maintenance of New Zealand pastured cows, and their associated low level of energetic efficiency, is due to the oxidation of excess nutrients consumed, it is to be expected that the metabolic rate of such animals would be raised appreciably above the normal. Calorimetric experiments to determine whether in fact this occurs have therefore been conducted and the results will be briefly summarised and discussed.

It should perhaps be emphasised that in this connection we are not concerned with the "basal metabolism", which represents the basic and irreducible heat production when the animal is in a thermo-neutral environment, expending the minimum of voluntary energy, consuming no food, and in the fully post-absorptive state. These rigorous conditions are exceedingly difficult to attain in the ruminant since even in the fasted animal a period of 72–96 hours is usually required to terminate the fermentative processes in the rumen, unlike the human where the post-absorptive condition is generally attained in 12–18 hours after the last meal. Furthermore, consideration of dairy cow efficiency requires that the metabolic determinations be made on cows *actively lactating* and, clearly, the abstention from feeding requisite for attainment of the true basal state is incompatible with the continuance of lactation as the milk secretion diminishes sharply as fasting continues.

The requirement for our present purposes is, therefore, determination of the heat production of the fully fed and still lactating cow, and hence it represents the basal metabolism, plus the heat increment of feeding, plus the energy cost of milk synthesis. Opportunity was taken, as part of a wider series of investigations concerned with the energy metabolism of dairy cows, to conduct such determinations, the specific purpose being to test the hypothesis that the feeding of highly improved pasture evokes a pattern of energy metabolism capable of explaining the apparent greater waste of nutrients by thermogenesis in pasture-fed cows compared with those stall-fed on compounded rations.

Material and Methods

Forty cows were selected from those available and randomly split into two groups of 20 each. One group (A) was grazed on fields of highly improved ryegrass/clover pastures and the other group (B) on a number of old pastures containing a low proportion of clovers and a mixed assortment of grass species of inferior agronomic merit. The last-mentioned grazings were, indeed, of a markedly inferior nature; they had received only scanty fertiliser dressings at irregular intervals over several years and were shortly to be ploughed up and re-sown. Yet despite the apparent low fertility of these areas, they had for a long time formed part of the grazing rotation and were considered to be satisfactorily productive, an opinion supported by the fact that there was no appreciable decline in milk yield during periods when these pastures had been exclusively grazed, and it was claimed that the cows remained healthy on them.

Each animal was examined twice daily, when the rectal temperature, heart rate, respiration rate, and thoracic girth was measured and recorded. Heart rates were obtained with the stethoscope applied to the left chest-wall in proximity to the heart as palpation of surface arteries had consistently been found unsatisfactory. Separate milk production records were kept in respect of each cow throughout three months of established lactation.

The time of the examinations was so selected that an appreciable interval had elapsed since feeding terminated and if the animal was not then recumbent, and had not been so for some time, an adjustment in the recorded heart rate was made by reducing the observed rate by 5 beats per minute, as suggested by a large series of observations.

Metabolism Determinations

In addition to the clinical observations just mentioned, a number of cows from each group, selected on the basis of docility, ease of handling, muscular repose, and amenability to the apparatus, were used for frequent determinations of their respiratory exchange. The resting-lactating metabolism was determined by indirect calorimetry, using a rubber face mask connected to a large oxygen spirometer by tubes for the conveyance of expired and the inspired air, regulated by valves which cause the air to flow in one direction through the apparatus. In this type of instrument the expired air is freed of carbon dioxide by passage through a vessel charged with porous soda lime, and the

rate at which oxygen is consumed over a time period is automatically recorded on a kymograph attached to the machine. By using this covenient mechanism, calculation of the respiratory quotient (R.Q.) is dispensed with and, instead, an R.Q. of 0.82, corresponding to the average caloric value of 4.825 kcal per litre of oxygen, is conventionally assumed.

It will be appreciated that ruminants produce large quantities of carbon monoxide as a result of bacterial fermentation in the rumen and since it is not possible by oral collection to distinguish the CO_2 of digestive origin from that arising from respiratory metabolism, the R.Q., if determined, would be misleading and hence, in the case of ruminants not reduced to the post-absorptive level, the rate of oxygen consumption undoubtedly provides the most accurate measure of their heat production. With the rate of oxygen consumption over the selected time, duly corrected for temperature and pressure, the energy metabolism in kilocalories is the product of this rate and the factor 4.825, corresponding to the assumed R.Q. of 0.82.

RESULTS

The mean "resting" *non-lactating* heat production of the 15 animals in Group A (highly improved pasture) was determined just prior to breeding and found to be 2190 kcal per sq. metre of surface area, and the mean heart rate at this time was 67.3 per min. Similar values for the 11 cows in Group B (unimproved pasture) were 1808 kcal per sq.m. and a mean heart rate of 59.4 per min.

During the month of peak *lactation*, the average heat production of Group A cows increased to 15,593 kcal/24 h, or 3793 kcal/sq.m., and Group B cows to 12,610 kcal/24 h, or 3049 kcal/sq.m. The mean heart rate of Group A animals was observed to have increased to 77.3 per min, or a rise of 10 beats per min, while those of Group B advanced to 64.9, an increase of 5.5 per min.

The detailed results are summarised in the following tables, where the measured oxygen consumption of each animal is shown, computed for 24 hours and corrected for standard temperature and pressure. The heat productions are shown in three forms: (a) total kilocalories, (b) kilocalories per "physiologic unit" of weight, i.e. the 0.73 power of live weight, and (c) kilocalories per sq. metre of surface area (s.a.) — the latter computed by the formula connecting surface area of cattle with body weight: s.a. $= 0.096\ (w)^{0.56}$, with the live weight (w) expressed in lb.

DISCUSSION

It will be seen from Table 3 that the average heart rate of lactating cows grazing unimproved pastures (our Group B) was 64.9 beats per min, which is in close agreement with the observations of Thomas and Moore (1952), of the U.S. Department of Agriculture, who found that the mean heart rate of barn-fed cows receiving normal nutrition was 64 per min in mid-lactation. This would seem to imply that the nutrient intake derived from the unimproved pasture was close to actual requirements, both in quantity and quality. Such being the case, it will be

TABLE 2. RESTING-LACTATING HEAT PRODUCTION OF DAIRY COWS GRAZED EXCLUSIVELY ON "IMPROVED" PASTURES (GROUP A)
(during month of Lactational Peak)

Cow No.	Weight (lb)	O_2 Consumed (Lit/24 h) S.T.P.	Heat Production (24 h)			Heart Rate per min	Mean F.C.M. lb/day
			Total Kcal	$\frac{\text{Kcal}}{W^{0.73}}$	Kcal per sq. m.		
20	798	3233	15,600	118.76	3836	78	32.8
22	832	3390	16,400	121.13	3941	80	34.1
23	830	3285	15,850	117.26	3813	77	34.3
25	826	2984	14,400	106.89	3473	71	28.2
26	787	3181	15,350	118.04	3804	77	32.5
27	817	3254	15,700	117.48	3811	77	31.7
28	843	3440	16,600	121.38	3958	81	34.8
30	791	3057	14,750	113.04	3646	74	28.4
32	805	3088	14,900	112.67	3645	74	27.7
33	824	3316	16,000	118.97	3864	79	33.2
34	817	3390	16,400	122.72	3980	84	35.0
36	815	3368	16,250	121.85	3950	80	33.9
37	822	3295	15,900	118.43	3845	78	33.3
38	809	3078	14,850	111.92	3624	74	29.1
39	785	3098	14,950	115.16	3710	75	29.8
Means:	813	3230	15,593	117.05	3793	77.3	31.9

TABLE 3. RESTING-LACTATING HEAT PRODUCTION OF DAIRY COWS GRAZED EXCLUSIVELY OF UNIMPROVED PASTURES (GROUP B)
(during month of Lactational Peak)

Cow No.	Weight lb	O_2 Consumed lit 24 h, S.T.P.	Heat Production (24 h)			Heart Rate per min	Mean F.C.M. lb/day
			Total Kcal	$\frac{\text{Kcal}}{W^{0.73}}$	Kcal per sq. m.		
1	789	2429	11,720	89.98	2900	59	27.2
3	822	2528	12,200	90.87	2948	62	28.8
6	807	2614	12,610	95.19	3061	65	31.0
7	796	2607	12,580	95.93	3100	64	31.3
10	851	2665	12,860	93.40	3048	66	30.5
11	834	2696	13,010	95.93	3120	68	31.9
12	796	2504	12,080	92.12	2976	63	29.1
14	849	2684	12,950	94.24	3077	66	33.6
16	825	2678	12,920	96.00	3121	67	33.2
17	833	2617	12,630	93.18	3028	66	28.9
19	832	2728	13,160	97.18	3163	68	31.4
Means:	821	2614	12,610	94.00	3049	64.9	30.6

convenient to regard the cows in Group B as constituting a 'control' group with which to compare the performances and responses of the other group which was grazed on highly improved pastures.

Attention will now be drawn to several interesting features which emerged in these investigations.

Heat Increment of Lactation

It is common knowledge that cows consume a greatly increased quantity of food during lactation and consequently a concurrent increase in heat production, or oxygen consumption, is to be expected. Additional sources of heat production include the energy expended in converting the several milk precursors into milk, the energy-cost of maintenance of the hypertrophied and active mammary gland, and the cost of maintaining a higher level of endocrinal activity. Of these several sources, the greater feed turnover is the most potent, but it is also apparent that endogenous lactogenic hormones must exert an important effect upon metabolism. In this connection, it has been shown by many workers that thyroxine or its synthetic analogues, which are among the most powerful activators of energy metabolism, greatly stimulate milk production, from which it can be inferred that the activity of the thyroid is increased during lactation.

In our experiments, the augmented feed consumption and increased endocrine activity resulted in an increase in the heat production, termed the "heat increment of lactation", of an average of 73.2% in Group A cows and 71.4% in the 'controls' which compares with a mean lactational increment of 67% reported by Brody and his associates (1948) for Jersey cows housed and stall-fed.

Resting Metabolism and Milk Yield

In general, the milk yield was observed to be proportional to the heat production, and not to the body weight, but the rate of metabolism increased more sharply than did the milk yield, as might perhaps be expected by operation of the law of diminishing returns. However, many discrepancies appeared in these interrelationships, which might be due to experimental errors in our data and to variability arising from differences in individual characteristics among the animals. Moreover, while stable metabolic values can be obtained in the fully post-absorptive state under rigidly standardised conditions, the resting heat production of cattle is apt to be much less stable as it is affected by environmental factors and the physiological condition of the animal.

Resting Metabolism and Heart Rate

It is well known that the cardio-respiratory activities tend to parallel changes in the overall metabolism, and the heart rate may, indeed, be used to compute an approximate estimate of the heat production. It is of some interest therefore to note that regression analysis of the data indicated that the recumbent heart rate was proportional to the total resting heat production of the lactating cows and could be estimated with some precision by means of the following equations:

$$M = 200P + 133 \quad (r = 0.971) \text{ for Group A cows}$$
$$M = 150P + 2870 \quad (r = 0.949) \text{ for Group B cows,}$$

where "M" is the resting heat production in kilocalories per 24 h, and "P" is the observed pulse rate per min.

Similar analysis showed that the heat production of both groups combined could be predicted by:

$$M = 215P - 1200 \quad (r = 0.973)$$

Having regard to the known variability of the resting-lactating metabolism and the difficulty in obtaining precise results, these studies suggest that the heat production of such animals can probably be estimated with a degree of accuracy sufficient for all practical purposes simply by multiplying the pulse rate by 200 (i.e. $M = 200P$). On the average, this understated the heat production of the Group A cows by only 1.6% and overstated that of the Group B cows by 3%.

Resting Metabolism and Nutrition

It can be seen from the tabulated results (Tables 2, 3) that the mean heart rate of the cows grazed on highly improved pastures was 19% higher, and their mean resting metabolism was 24% higher, than that of the 'controls'. On the average, their production of fat-corrected-milk was 4.3% greater than the 'controls'. This difference is so small as to exclude the possibility that their increased metabolism was merely an associative effect of higher milk output from the grazing of "improved" pasture swards.

The results leave little room for doubt that some nutritional effect arising from the consumption of these pastures was the principal factor leading to such a significant increase in the metabolic rate, and its accompanying production of waste heat. Indeed, taken in conjunction with the high feed intakes and reduced food-conversion efficiency of the cows in the Ruakura studies fed on typical high-production pastures, the inference that such pastures are capable of inducing excessive thermogenesis would seem to be an inescapable conclusion.

Studies in which the "quality" of two contrasting types of pasture has been compared, appear to be very few in number, but one experiment reported by W. S. Gordon (1948) from the United Kingdom lends some support to the general thesis now postulated. He reports that the heart rate of 24 horses recorded daily over a period of more than 12 months was within the range of 40–50 per min while they were yarded and fed on oats and hay, but was observed to rise sharply to a mean of 78 whenever they were turned on to "good" pasture and to about 58 when they were grazed on an old pasture. The animals were frequently switched from one type of feeding to the other throughout his experiment and the change to improved pasture was always followed by a pronounced elevation in the heart rate, indicating an increased rate of metabolism.

Evidence of Hyper-metabolism

Many experiments have shown that underfeeding, either deliberately induced or naturally-occurring, results in a reduction in the rate of metabolism. Conversely, if the amount of consumed food exceeds natural requirements or the ability of the animal to metabolise it to useful purposes, or if the food is unbalanced in its composition of essential dietary components, then the rate of metabolism is increased. The effect of excess feeding at various levels was measured by Thomas and Moore (1952) and they found that over a complete lactation the accelerated heart action was roughly 1 beat per minute for each 2%

increase in feed intake above requirements (or more accurately, 4 beats per min for each 7.7% increase in nutrients). When the food intake was reduced there was an immediate fall in the heart rate, which they found to be in direct proportion to the total metabolism of the animal.

If this finding be applied to our Group A cows, whose mean heart rate during their lactational peak was 12 beats per min higher than that of the 'controls', we obtain an indication that these cows probably consumed nutrients at a level slightly more than 23% above that at which they could usefully metabolise them. It will also be recalled that the mean heat production of the Group A cows was 24% in excess of the 'controls' (i.e. 3793 kcal/sq.m/day compared with 3049 kcal/sq.m/day). Furthermore, as was shown earlier in this paper, the feed intake of the Ruakura cows, after making a suitable allowance for grazing activity, was about 22% in excess of the amount necessary to meet all their requirements had they been fed compounded rations on the scale provided under accepted feeding standards.

Thus, it would seem that the hypermetabolism arising from the grazing of highly improved pasture was probably of the order of 22–24% in excess of the standard resting heat production to be expected of normally fed dairy cows.

THE CAUSES OF HYPER-METABOLISM

While the demonstrations just discussed are suggestive, they may not be conclusive, but they would appear to support the hypothesis that dairy cows grazed on highly improved pasture may consume feed of such a nature, or in such quantity, that their oxidative metabolism is accelerated.

If we exclude thyroid dysfunction and specific fevers, which of course are accompanied by a sharp rise in the metabolic rate, (roughly, by 13% for each degree C of fever), there appears to be no clinical basis for assuming that a moderate elevation of the heart rate, and enhanced metabolic rate, is pathologic in the usual sense. But on the other hand, if the heart rate is accelerated significantly beyond the normal range, and hypermetabolism is present, it is apparent that the animal is either receiving over-nutrition or the feed components are unbalanced; in either case there is excessive oxidation in the disposal of unusable nutrients.

It seems unlikely that frank overnutrition is the cause of the observed hypermetabolism since food energy consumed in excess of maintenance requirements would normally, in the lactating animal, be used for milk production (Brody 1945). In the true physiological sense, a state of "overnutrition" is not reached until the cow has exceeded her capacity to lactate, at which point the excess dietary energy is either dissipated by lavish oxidation as useless heat or deposited as fat. Neither in the Ruakura work nor in the observations now reported was there any evidence that the maximum milk secreting potential of the cows had been attained, let alone exceeded.

A large but variable proportion of the food energy is of course always lost as heat via the faeces, urine, fermentative gases formed in the rumen, and the heat increment of feeding -the so-called specific dynamic action (S.D.A.). It is therefore not available for conversion by the animal into a form of energy which results in a useful product, such as milk, meat, work, etc., but represents an unavoidable thermodynamic cost. The proportion so lost is at a minimum when the feed is perfectly balanced with respect to its various components: protein, energy, fat, minerals, and vitamins. On the other hand, the metabolic rate is raised and energy utilisation is impaired, if the diet is unbalanced by specific deficiencies. Since a deficiency of any one essential component means an unbalancing of the ration it follows that *any* deficiency will lead to an increase in the proportion of feed which is burned to no useful purpose.

It seems, therefore, that the most probable factors responsible for the impairment of the pasture-fed animal's efficiency in the utilisation of energy are: (a) a deficiency of one or more of the essential mineral elements or vitamins, and (b) an excessive proportion of dietary protein in relation to energy-yielding constituents. Of the two, the last-named would seem usually to be the more likely under New Zealand pasture conditions.

Effect of Protein : Energy Ratio on Metabolism

The relationship between protein and energy in the diet of animals, and its influence upon food-conversion efficiency, has been widely studied at research centres abroad but appears to have received little attention in New Zealand. Yet an excessively high protein content is one of the distinguishing features of our improved pastures, which frequently range as high as 35% of the dry-matter in the winter and early spring (Melville 1953) and have even been reported to exceed 40% (White *et al.* 1948).

The consumption of fodder high in nitrogen has been shown to cause a marked increase in the generation of useless heat. More than 50 years ago, Kellner (1909) observed accelerated cardio-respiratory action after the feeding of excess protein, while Lines and Peirce (1931) in the course of metabolism studies on sheep, found that on attainment of the basal state after 48 hours complete fast following high-protein feeding, the metabolism was still affected by such feed, being 18% higher than that following a lower protein diet. After 72 hours' fast it was still nearly 10% higher. Many other experiments confirm the thermogenic effect of high protein, an effect which is out of all proportion to that possessed by other feed components. Normally, a high proportion of the calories liberated in the combustion of carbohydrates and fats can be used to produce useful energy, but the cleavage products of amino-acids are considered to have a restrictive effect and thus a smaller proportion of the protein calories is capable of conversion into any form of energy other than animal heat.

There appears to be an optimum range in the protein:energy ratio within which the animal functions most efficiently. Probably the range is not a very narrow one but much experimental and practical evidence

indicates that the concept itself is sound. The findings of a large number of authorities have been summarised by Leitch and Godden (1941), of the Imperial Bureau of Animal Nutrition, and they conclude that the optimal intake of protein for ruminants is within the range of 15% to 20% of the total food. This level must often, if not usually, be much exceeded by dairy cows grazing typical highly improved pastures, with a heightened metabolic rate and reduced conversion efficiency as a consequence, since the greater the amount of nitrogenous food ingested in excess of needs the larger the amount of urea and ammonium salts which are formed, and the higher the loss by specific dynamic action.

EXCESS PROTEIN AND ANIMAL DISEASE

As mentioned earlier, there seem to be no substantial grounds for expecting that a high-protein diet will, of itself, directly provoke pathological lesions in farm animals, but the reduced energy intake which inevitably accompanies the ingestion of excess protein is evidently implicated in the genesis of certain metabolic disorders which affect sheep and cattle.

A full discussion of the underlying pathology concerned in the common metabolic disorders is somewhat outside the scope of this present paper, but it should be recalled that work at the Wallaceville Animal Research Station (N.Z. Dept. Agric. 1950) and field and laboratory studies by Blakely and Dewes (1942) and Swan and Jamieson (1949) have indicated the association between low-energy feeding and the incidence of milk fever, grass staggers, and ketosis.

Of special relevance in considering the effect of excess dietary protein upon the general metabolism is the work of Anison *et al.* (1954), Head and Rook (1955), Johns (1956) and others, which linked certain metabolic disorders with the harmful effect of high ammonia levels originating in the rumen. They showed that the production of excessive amounts of ammonia not only results in the wastage of nitrogen to the animal but may also give rise to toxic symptoms. When the ammonia concentration exceeds a certain level (*ca.* 60 millimoles per litre) the normal function of the liver in removing ammonia from portal blood is over-taxed and consequently its concentration in peripheral blood is raised and ultimately may reach a level at which toxic symptoms supervene. Even if no clinical disorder becomes apparent, high intakes of readily fermentable protein are capable of reducing the efficiency of overall metabolic activity and are now considered to be a primary cause of some of the ill-defined syndromes affecting lactating dairy cows.

In these mechanisms, the specific role of the symbiotic rumen microflora should not be overlooked. The primary requirements for the growth, proliferation, and digestive activities of these micro-organisms is an adequate supply of available carbohydrate, the fermentation of which not only supplies the host animal with its principal source of energy (i.e. the volatile fatty acids), but must also provide the micro-organisms with their essential energy substrate. Furthermore, as the synthesis of bacterial protein in the rumen is dependent upon the efficient functioning of the particular rumen bacteria concerned in

these transactions, it is evident that a net deficiency of carbyhydrate in the diet may produce two profound ill-effects by: (a) restricting the formation of volatile fatty acids in the rumen, thus provoking an energy deficiency in the animal, and (b) restricting the synthesis of bacterial protein, which is itself an important source of biological protein in the ruminant's economy.

In summary, therefore, it is apparent that the carbohydrate metabolism of ruminants is precariously balanced, and that marked deviations in either the quality of the diet or in the animal's requirements for energy can seriously disturb this balance and lead to a pathological condition.

Effect of Mineral Deficiencies on Metabolism

There appears to be a clear and definite relationship existing between the level of mineral nutrition and the overall energy metabolism. The physiological processes fundamentally involved are complex, and the pathology even more so, but it has been amply demonstrated that if any one of the essential mineral elements is deficient in the diet, the rate of energy metabolism may be accelerated by as much as 20–25%, depending upon the degree of deficiency (Hickey 1955). A factor that is most probably involved in this situation is that the maintenance of the animal body, and its output of useful products in the face of a dietary deficiency of indispensable mineral nutrients, usually evokes a compensatory abstraction of minerals from body tissues. Since the mineral composition of the soft tissues is held virtually constant, such abstraction can be achieved only at the expense of partial destruction of these tissues, and catabolism necessarily implies an increased metabolic rate with its associated homeostatic waste.

The subject of energy metabolism in relation to mineral deficiencies, especially of phosphorus, calcium, magnesium, potassium, iodine, and iron, was well reviewed 15 years ago by Max Kleiber (1945) but it would seem that little further progress has been made since then in the study of this specific problem. In view of the role now known to be fulfilled by inorganic elements, including the trace minerals, in the functioning and proliferation of rumen microorganisms, it is clearly desirable that this aspect of the matter should receive renewed attention. In the present state of knowledge, however, it is not possible to assess with accuracy the part which may be played by mineral deficiencies in contributing to the hypermetabolism which apparently is a characteristic of ruminants grazed on certain types of pasturage.

Conclusions

The calorimetric determinations reported in this paper appear to support the hypothesis that dairy cows grazed on typical highly improved New Zealand ryegrass/clover pastures exhibit an unduly high rate of thermogenesis when so fed, thus impairing the efficiency with which they convert such fodder into useful dairy products.

From the nutritional standpoint, the conclusion which emerges from these studies is that the very high nitrogen level characteristic of

these improved pastures is probably the principal factor contributing to the high rate of thermogenesis shown by animals fed on such pastures and to the reduced efficiency with which they convert their food.

In their comprehensive studies of the efficiency of farm animals in converting their feedingstuffs into food for man, Leitch and Godden (1941) showed that dairy cows in the United Kingdom grazed upon typical good pasture containing about 20% protein would consume grass at a daily level which would furnish enough energy to produce only 4 gallons of milk but enough protein to produce 8 gallons. They pointed out that this surplus of protein implied a large loss of energy in the form of useless heat, with of course a lower efficiency of energy conversion. It is evident that improved New Zealand pasture herbage with a protein content appreciably higher than 20% would inevitably mean correspondingly greater waste of nitrogenous components and higher loss of energy by thermogenic action.

It is, of course, possible that other factors are involved in this situation, such as disorders of the complex reactions in plant tissue which result in the formation of a multitude of chemical compounds, or of the enzyme transactions within the animal body which participate in the synthesis of useful products. Our knowledge of these reactions is lamentably weak at the moment, whereas the simpler fact has been well established, namely, that the level of nitrogenous constituents in high-production pastures is often unnecessarily high.

If unduly high levels of pasture protein are responsible for placing the grazing animal at a physiological disadvantage by seriously impairing its metabolic processes, the animal industry is entitled to look to the plant breeders and pasture ecologists to provide the remedy since, in the New Zealand environment, they are the animal nutritionists in every practical sense of the word.

A leading pasture authority (Melville 1953) has conceded that the use of improved strains of grasses and clovers has resulted in an increased incidence of metabolic disorders in farm animals and, among other possible factors, implicated high levels of nitrogenous compounds in the pasture plants. However, he questioned the feasibility of breeding plants with a lower protein content in their leaves and considered that rectification of the energy:protein imbalance should be sought by other means. If this is so, the feeding of concentrates or roughage to supplement and dilute the pasture diet during at least the peak period of lactation might be worthy of consideration as it is unlikely that the industry would favour a reversion to less-improved types of pasture. If such feeding is not practicable, an adjustment in grazing management whereby the pasture is fed at a more mature stage of growth might be of assistance in restoring the dietetic balance.

But whatever may be the causes that contribute to the apparent imbalance among the dietary factors contained in improved pasture, it is evident that such fodder fails in some manner and in some measure to meet the optimum feed requirements of grazed dairy cows. It is therefore clearly desirable that the nutritional physiology of pasture-

fed ruminants, as it is affected by the complex interactions between plant and animal, should receive more intensive study than has hitherto been accorded it. These interactions obviously pose many problems of both an economic and a physiological nature and it is of some importance that they should be clarified so that we may proceed intelligently towards their solution.

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EFFECT ON HONEY BEES OF SOME CHEMICAL WEEDKILLERS

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Summary

The butyl and butoxyethanol esters of 2,4,5-T (2,4,5-trichlorophenoxyacetic acid) are hormone weedkillers in common commercial use. The effect of these substances on honey bees was tested in the laboratory, in observation hives, and in the field. Their use does not constitute a hazard to bees.

The two principal defoliants used at present on white clover are a mixture of 50% dinitro-ortho-secondary-butyl-phenol (D N B P) plus 10% dinitro-ortho-secondary-amyl-phenol (D N A P) and a 40% solution of penta-chloro-phenol (P C P). These phenolic weedkillers are toxic to bees, but highly repellent and so unlikely to be picked up directly on a crop by bees. However, during application, some bees might be sprayed and poisoning of other bees through contact or fumigant action might then occur inside the hive. Experiments conducted in observation hives clearly showed that only bees actually sprayed died and there was no transfer of poison or lasting hive disorganisation.

Introduction

New Zealand has a highly developed beekeeping industry which supplies an essential service to agriculture. The careless use of agricultural chemicals could cause sufficient bee mortality to weaken the industry and lead to a drop in seed production and inefficient pollination of clover pastures. So the New Zealand Department of Agriculture has studied the effect on honey bees of a wide variety of agricultural chemicals (Palmer-Jones and Forster 1958a). Information gained in these trials has enabled recommendations to be made for the safe use of agricultural chemicals.

The effect on honey bees of chemical weedkillers was studied by Palmer-Jones (1950) in laboratory tests and by Palmer-Jones and Forster (1958b) in both field and laboratory tests. It was thought possible that the presence of chemical weedkillers on the bodies of bees entering a hive might poison other bees or brood by fumigant or contact action. In addition, sprayed bees could have an uncharacteristic hive odour and might be liable to attack by their fellows with consequent disorganisation of the hive. These effects could only be studied by the use of observation hives. Trials are now described in which observation hives were used in conjunction with the other methods.

Hormone Weedkillers

Hormone weedkillers are widely used for the control of gorse, bracken, blackberry, lupin, and Californian thistle.

Bees could be sprayed with these while visiting flowers on plants being treated; drifting spray could reach bees on other plants or clover pasture; finally drifting spray could envelop hives and might affect brood. Once plants have been sprayed the flowers rapidly wither and lose their attractiveness to bees and the dieselene, often used as a diluent, acts as a repellent (Palmer-Jones and Forster 1958b).

Experimental

The butyl and butoxyethanol esters of 2,4,5-T (2,4,5-trichlorophenoxyacetic acid) and M C P B (2 methyl, 4 chloro-phenoxy butyric acid) were tested. Commercial preparations were used, being diluted to a strength of 1 in 40 (acid equivalent).

Laboratory Tests. The direct spray effect of the hormones on bees was studied by the method described by Palmer-Jones (1958). Bees were sprayed with sufficient of the hormones to ensure that they were covered with fine drops. After spraying bees were caged with feeders of sugar syrup and mortality noted after 24 hours (Table 1).

TABLE 1. Toxicity of Hormone Weedkillers as Sprays

Hormones: 1 in 40 (acid equivalent)	% mortality for each cage (of 50 bees)
2,4,5-T butoxyethanol ester	8, 4, 2, 8
2,4,5-T butyl ester	2, 0, 2, 0
M C P B	0 0 0 0

It is apparent from the table that sprays of the butoxyethanol ester of 2,4,5-T would cause only slight mortality while the butyl ester of 2,4,5-T and M C P B would cause none.

Studies in Observation Hives. Two-frame observation hives were used, one frame being above the other so that all parts of the combs were open to inspection (Fig. 1). Removable wooden shutters shielded bees from the light when they were not being inspected. Each hive used held about 2,000 bees and contained brood in all stages of development. They were headed by vigorous laying queens. Although the observation hives were kept inside the laboratory their entrances were connected with the outside by tubes so that bees could leave freely. At the time of the experiments bees from both hives were actively collecting nectar and pollen.

Foragers returning to an observation hive were heavily sprayed at the entrance with butyl and butoxyethanol esters of 2,4,5-T and M C P B. About 200 foragers were sprayed with each hormone on separate days. It was observed that the sprayed bees in each case entered the hive normally and were freely accepted by the bees inside which were unaffected.

Two batches, each of 40 field bees from an observation hive, were anaesthetised with CO_2, marked on the thorax with coloured commercial

nail varnish, sprayed with one of the above three hormones, and returned to the hive (Fig. 2). Spraying with each hormone was carried out on different days. Marked bees were accepted freely by the hive bees

Fig. 1.—Observation hive.

which were unaffected. For several days after spraying the majority of marked bees were observed acting as foragers.

The queen continued to lay throughout the tests and brood in all stages was unaffected.

One hundred and sixty unsprayed control bees were similarly unaffected.

Fig. 2.—Marked bees in observation hive. Marking enables their behaviour to be studied after they have been sprayed with a chemical weedkiller.

Field Tests. Direct Spraying of Hives. The two 2,4,5-T and the M C P B preparations were sprayed separately over the entrances of strong hives. At the time of spraying the weather was suitable for maximum bee activity and many field bees were leaving the three hives. The hive entrances were so heavily sprayed that the hormones ran down the fronts of the hives and alighting boards. Many bees entering and leaving the hives were sprayed.

No adverse effects were observed over a period of several months.

Field Tests. Direct Spraying of Brood. Frames of brood in all stages of development were removed and sprayed: four from one hive with the butoxyethanol ester of 2,4,5-T, three and a half from another with the butyl ester of 2,4,5-T, and five from a third with M C P B.

No adverse effects were observed.

Phenolic Weedkillers

The two principal defoliants used at present on white clover are a mixture of 50% dinitro-ortho-secondary-butyl-phenol (D N P B) plus 10% dinitro-ortho-secondary-amyl-phenol (D N A P); and a 40% soltion of penta-chloro-phenol (P C P).

Palmer-Jones and Forster (1958b) showed that although sprays of D N P B plus D N A P and P C P are highly toxic to bees these preparations are so repellent that bee mortality is not likely to occur. However, it is often necessary to use these substances to defoliate white clover at a time when this crop is highly attractive to bees. Under such conditions a few bees may be sprayed and subsequently return to their hive. The effect of phenolic weedkillers brought inside in this way was studied by means of observation hives.

Experimental

A mixture of two pints of D N P B plus D N A P in 10 gallons of dieselene and a mixture of 4 lb of 100% P C P in 10 gallons dieselene were tested. Both were commercial preparations.

The studies were made in observation hives only.

D N B P plus D N A P. About 200 foragers returning to an observation hive were heavily sprayed. Immediately afterwards the bees in the hive became excited; within 15 minutes at least 50 were in convulsions, dying, or dead. Most of these were mauled by the hive bees and dead bees were removed at once. Only bees actually sprayed died. Within an hour all were dead and the hive had returned to normal.

In another experiment similar results were obtained when 80 marked anaesthetised bees were sprayed and dropped into an observation hive.

P C P. Foragers returning to an observation hive were heavily sprayed as before. Sprayed bees died but did not show symptoms of poisoning for ten minutes, P C P acting more slowly than D N P B plus D N A P. The bees sprayed with P C P did not excite the hive to any extent.

In a separate experiment the effects observed when 80 marked anaesthetised bees were sprayed with P C P resembled those shown by bees sprayed with D N P B plus D N A P except that the hive was only slightly excited.

Discussion

Palmer-Jones (1950) concluded on the basis of laboratory tests that the sodium salt of M C P would not cause bee mortality when used as a weedkiller. It is now evident that the related butyric acid compound, M C P B, is safe to use, as are the butyl and butoxyethanol esters of 2,4,5-T.

Palmer-Jones and Forster (1958b) concluded that although D N B P plus D N A P and P C P were toxic to bees they could be used in safety because of their strong repellency. It is well known that bees transfer nectar or water from one to another within the hive. In this way a poison can be spread from a few returning foragers to many other bees, causing their death and disorganising the hive. Leppik (1951) had described such effects as being caused by certain insecticides of the parathion group. Crops sprayed with D N B P plus D N A P and P C P are so repellent to bees that there is small likelihood of these

substances being ingested by bees and acting in this way. However, during application, some bees might be sprayed in flight and poisoning of bees through contact or fumigant action might then occur inside the hive.

Present experiments in observation hives clearly showed that only bees actually sprayed died. Sprayed bees would not have the usual hive smell but would smell strongly of the phenolic weedkillers so leading to their being treated as robbers. However, no lasting hive disorganisation occurred although they were sprayed much more heavily than would be likely in the field.

The use of observation hives in studying the effect upon bees of chemical weedkillers proved highly successful and will be extended when other agricultural chemicals are screened.

Acknowledgment

Mr. A. L. Bryant, Animal Research Station, Wallaceville, took the photographs.

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PHOTOSENSITIVITY DISEASES IN NEW ZEALAND

XXI. THE SUSCEPTIBILITY OF THE RABBIT TO FACIAL ECZEMA

By D. C. Dodd, Ruakura Animal Research Station, Department of Agriculture, Hamilton

(*Received for publication, 7 April 1960*)

Summary

Facial eczema damage in the rabbit is essentially the same as that in the sheep and guinea pig, but the lesion in the rabbit is much more acute and develops more rapidly.

The essential feature is an acute cholangitis characterised by periductal oedema, fibrosis, and cellular infiltration. The extra-hepatic biliary system is markedly affected. The degree of oedema and fibrosis is proportional to the size of the duct. The smallest duct branches often show no change.

Occlusion of medium-sized ducts and proliferation of bile ductules proximal to the site of occlusion is also seen.

Branches of the portal vein and hepatic artery become involved in the inflammatory process and damage to the wall of these vessels sometimes occurs.

Introduction

Brief reference has previously been made by Filmer (1958) and Dodd (1958) to the fact that the liver of the rabbit is susceptible to damage by facial-eczema toxin. The preliminary work done at this station on the experimental feeding to rabbits of toxic grass, the facial-eczema fungus *S. bakeri,* or extracts therefrom, has been reported by Clare (1959). The purpose of this paper is to give a general picture of the gross and histological changes that have been seen in the livers of the rabbits used by this worker.

Materials and Methods

The livers described herein were obtained from the rabbits referred to by Clare (*loc. cit.*) and were examined immediately after the animal was killed or as soon as possible after death. At least three sections cut at right angles to the main bile channels were taken from each liver for histological examination and were fixed in 10% formalin. After fixation they were processed through an automatic tissue-processing machine and embedded in paraffin. The sections were cut at a thickness of approximately five microns and then stained with haematoxylin and eosin.

Morbid Anatomy

Most livers have shown little external change other than oedema of the extra-hepatic biliary system (Fig. 1). This oedema has varied from very slight to very marked and has borne a fairly direct relationship to the amount of toxic material consumed by the animal. In the most severe cases the ducts may be as much as 4–5 mm diameter

whereas normally they are less than 1 mm diameter. Rarely has the oedema involved the wall of the gall bladder and then only for a distance of a few millimetres, but in severe cases it can be seen to extend the full length of the common bile duct to its entrance to the duodenum. No gross change has been noted in the duodenal mucosa at this site.

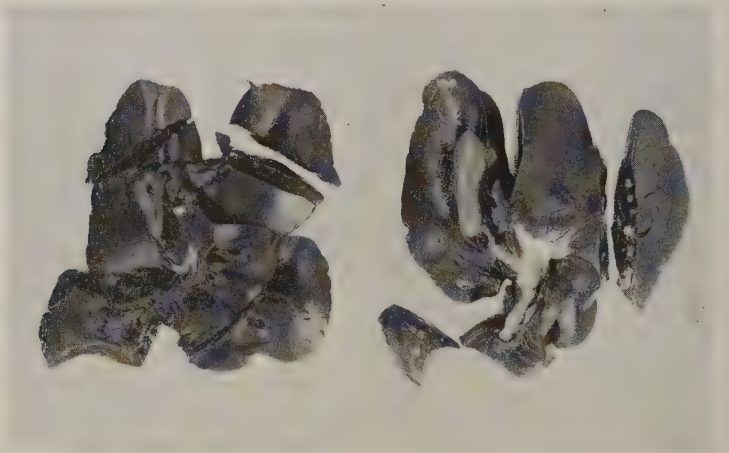

Fig. 1.—Affected liver on left, normal on right. Note gross oedema of extra-hepatic ducts and prominent white ducts within parenchyma.

In all but the most mild cases, localised aggregations of golden-yellow granular material were seen in the extra-hepatic ducts and floating free in the gall bladder, but they did not impede the flow of bile from the bladder nor along the ducts when the former was pressed with the finger.

These changes are the most constant of those that are apparent externally. Occasionally, however, other changes occur. In rabbits that lived for a long period some mottling and fibrosis was seen around the border, similar to the mottling seen in sheep and guinea pig livers affected with facial eczema. Distinct jaundice has developed in the livers of a few rabbits that have received a high level of toxic material over a short period.

When sections were made through the lobes of the liver transverse to the direction of the main bile channels, thickened oedematous ducts were again a prominent feature (Fig. 1), but the parenchyma usually appeared to be normal. If one of these very thickened ducts lay near the surface of the liver it could sometimes be seen through the capsule as a yellowish area as in hepatic coccidiosis (Fig. 1). The sectioned intra-hepatic ducts often contained yellowish granular material, identical with that seen in the extra-hepatic ducts. The degree of thickening and oedema of the ducts was in direct proportion to the size of the

duct and the damage has always been fairly evenly distributed through the various lobes.

HISTOPATHOLOGY

The most striking feature seen in histological preparations is a marked periductal oedema and fibrosis affecting the main bile channels (Fig. 2). This lesion may extend to the smallest portal systems but frequently no change is seen in them even when severe damage has taken place around larger ducts. The reaction is of an acute inflammatory type and has the characteristic appearance of granulation tissue. Numerous fine capillaries are present, and variable numbers of small and large mononuclears, plasma cells, and polymorphs invade the area.

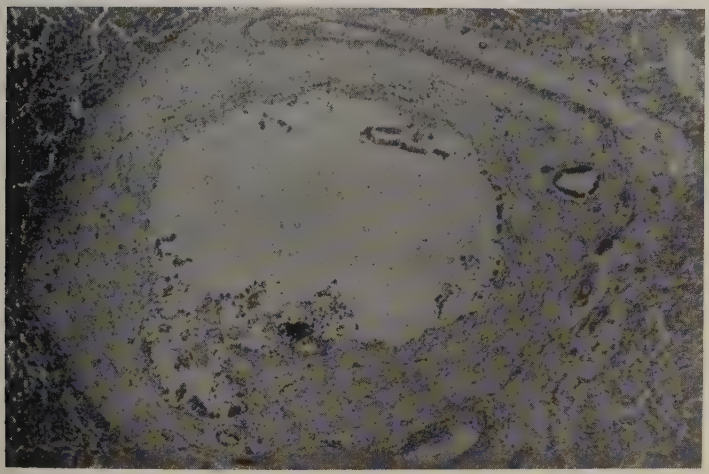

Fig. 2.—Marked periductal oedema and fibrosis with almost total destruction of duct epithelium. H. and E. × 50.

The biliary epithelial cells are damaged to a varying extent, and all stages from early degeneration to total necrosis and desquamation may be seen (Fig. 2). It is common to find necrosis of part of the wall of a duct and the site filled by a dense mass of acellular material which bulges into the lumen on one side and into the inflammatory tissue on the other (Fig. 3). In H. & E. stained sections this material stains irregularly; it tends to be basophilic but some parts are eosinophilic. The combination of necrosis of a duct wall, periductal oedema and fibrosis, and the presence of this debris can lead to occlusion of a duct (Fig. 4). The sequel to duct occlusion is proliferation of ductules in portal areas proximal to the site of occlusion (Fig. 5). The degree and extent of this proliferative change is much less prominent in the rabbit liver than in either the sheep or guinea pig liver. This is no doubt because in the rabbit the lesion is a far more acute one than it is for an equivalent dose of toxic material in the other two animal species, and usually results in death before ductule proliferation is marked. This

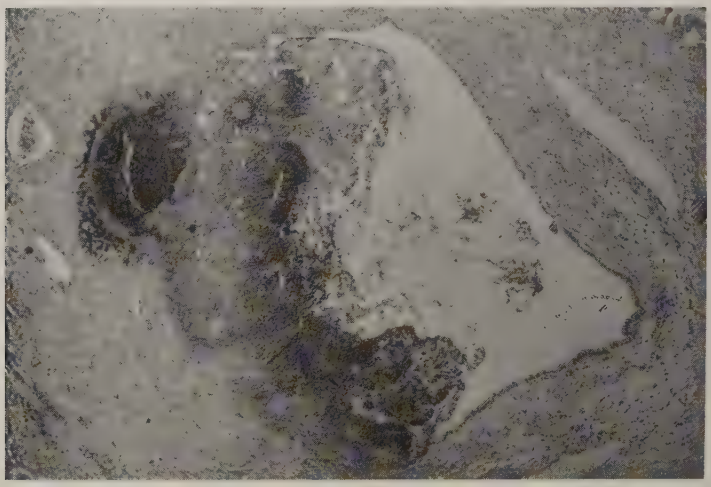

Fig. 3.—Large mass of necrotic debris bulging into lumen of large bile duct where wall has been destroyed. H. and E. × 50.

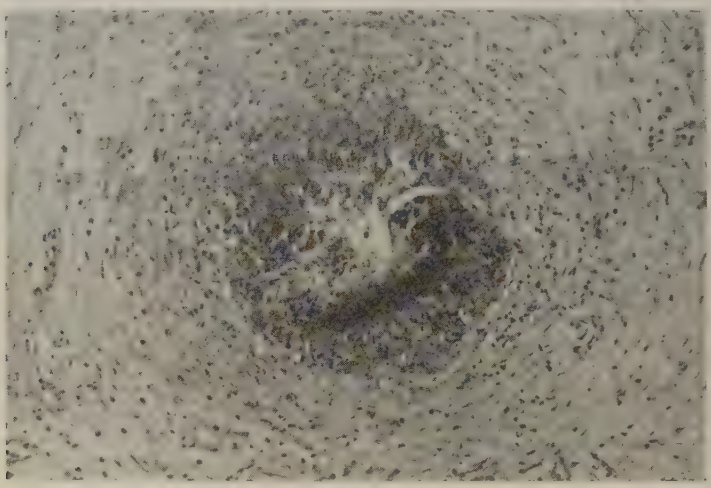

Fig. 4.—Medium-sized bile duct almost occluded by necrotic debris and surrounded by granulation tissue. H. and E. × 133.

is supported by the fact that duct proliferation becomes a more obvious lesion as time of survival increases.

No specific changes have been noted in the parenchymal cells except for the occasional appearance of focal areas of coagulation necrosis.

The branches of the portal vein and hepatic artery can also become involved in the inflammatory process and when there is a

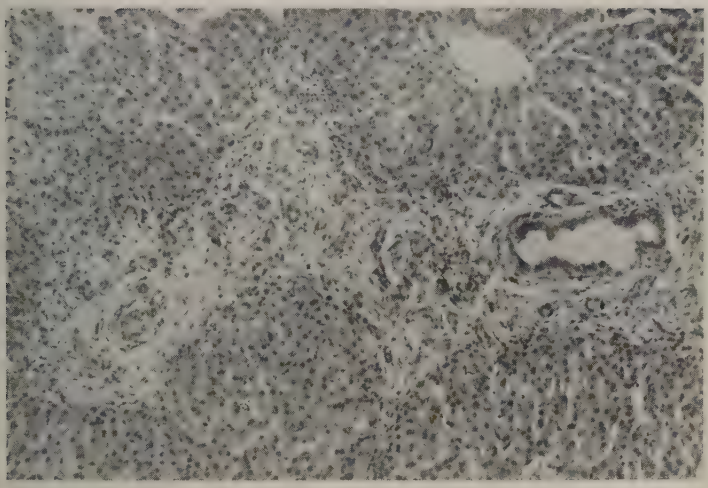

Fig. 5.—Anastomosing proliferating bile ductules in fibrous tissue in enlarged portal area. H. and E. × 133.

moderate to marked periductal oedema, they too are encompassed by granulation tissue. Actual damage to the walls of vessels in the portal triads is also a common finding (Figs. 6 and 7). At this stage it is not clear whether the vascular damage is a direct effect of the action of the toxin or whether it is simply the result of these vessels being associated with an acute inflammatory reaction. The vascular lesion begins with

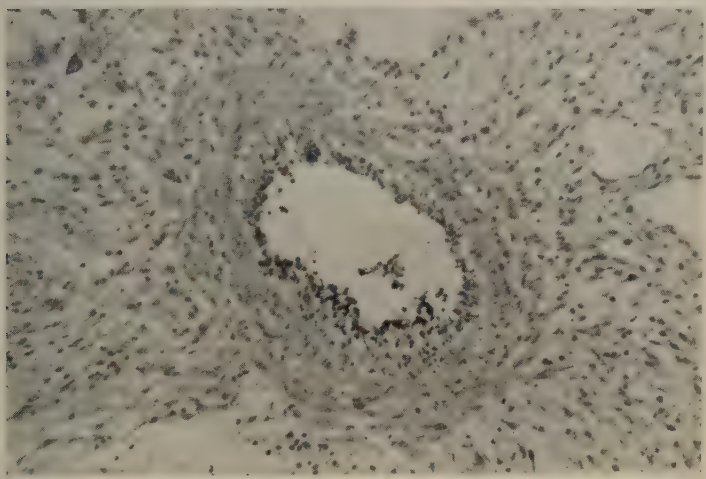

Fig. 6.—Branch of hepatic artery. Oedema and vacuolation of media and intima with heavy infiltration of small round cells. H. and E. × 133.

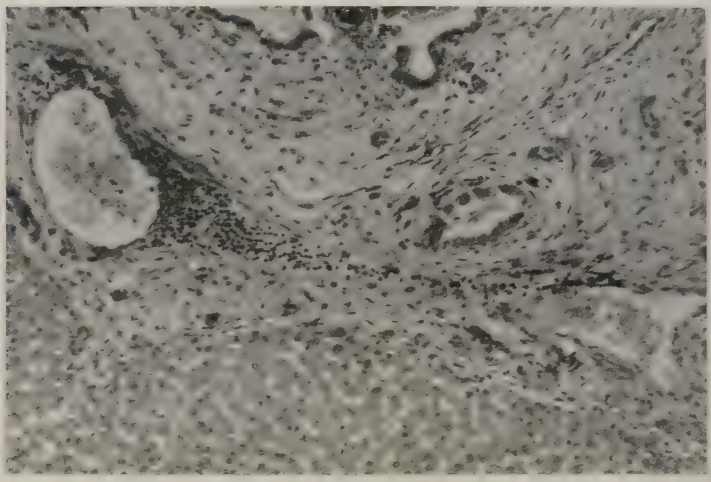

Fig. 7.—Branch of portal vein passing from left to right at lower part of enlarged oedematous portal area. Note concentration of small round cells in wall of vein.

a perivascular concentration of lymphocytes (Fig. 7) which later migrate through the adventitia and media to be found in the intima (Fig. 6) which develops a rough irregular border. Focal or diffuse degeneration of the media with swelling of the fibres and loss of stain affinity may also occur. As a result of damage to walls of portal veins thrombus formation develops in some areas. Similar vascular lesions have been described in sheep by Done *et al.* (in press).

Discussion

Since the time of the work reported here considerable advances have been made in studies on facial eczema.

Improved techniques in culturing the fungus *S. bakeri* and the isolation from it of the toxin, sporidesmin, have made it possible to dose rabbits and guinea pigs with accurately graded doses and to study the development of the lesions. This early work, however, does give some indication of the pathogenesis and supports the theories previously advanced by Evans *et al.* (1957), following their work with guinea pigs.

No difference can be detected in gross specimens or histological sections in the lesions caused by toxic grass, cultures of *S. bakeri*, or ether extracts of fungal cultures.

Other points relevant to the discussion have already been covered by Clare (*loc. cit.*) and need not be reiterated.

The pathology of this disease in the rabbit liver is essentially the same as that in the sheep and guinea pig, though the lesion in the rabbit is more acute and develops more rapidly.

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THE ESTIMATION OF SULPHATE IN PLANT MATERIALS AND BLOOD

By K. G. Hogan and J. N. Breen,* Animal Research Station, Department of Agriculture, Wallaceville

(*Received for publication, 7 April 1960*)

Summary

Methods for determining sulphate in plant material and blood are discussed. Modifications of a method based on the formation of methylene blue are described. This method is suitable for routine analysis of large numbers of samples.

Introduction

In investigations of the effects of inorganic sulphate on molybdenum and copper metabolism (Cunningham and Hogan 1959a; 1959b) the need arose for a rapid and accurate method of determining small amounts of inorganic sulphate in stock feeds and blood. Three methods were tried, a gravimetric barium chloride method, a benzidine colorimetric method and a hydrogen sulphide-methylene blue colorimetric method.

Barium Chloride Method

The barium chloride method investigated was that described by Woodman and Evans (1933). It relies on extraction of the sulphate from the sample with 25% hydrochloric acid (one volume of concentrated hydrochloric acid made up to four with water) and its subsequent precipitation as barium sulphate which is collected on a porcelain filter and weighed after ignition. Gooch, alundum, sintered glass, and porcelain crucibles with porous bottoms were tried for collecting the precipitate. Barium chloride became deposited in the alundum crucibles in spite of repeated washings and gave high results. Sintered glass crucibles were sensitive to temperature changes and liable to crack. Gooch crucibles took time to prepare and often failed when subjected to prolonged suction. Porcelain crucibles were free from these disadvantages. With the reservation that the method is subject to certain interferences (Fales and Thompson 1939) it was found to be generally satisfactory for pastures where the sulphate concentrations were greater than 0.25% on a dry-matter basis. However, it lacked the sensitivity required for our purposes and was not suitable for blood or plant material containing only microgramme quantities of sulphate.

Benzidine Method

The benzidine method is based on the precipitation of sulphate by benzidine; the benzidine is hydrolysed and the liberated benzidine dazotised and coupled with a phenol (Cuthbertson and Tompsett, 1931). The colour of the dye formed in this way is used as a measure of the sulphate in the pasture.

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The number of operations required and the amount of apparatus used made it quite clear that this method was not suitable for the analysis of large numbers of samples and the method was abandoned.

Methylene Blue Method

Johnson and Nishita (1952) have described a method in which the sample is digested in a special distillation digestion apparatus with a reducing mixture composed of hydrogen iodide, formic acid, and red phosphorus. In a later communication (Johnson and Arkley pers. comm.) hypophosphorus acid is suggested as an alternative to red phosphorus. The sulphuretted hydrogen resulting from the reduction of sulphate is carried through a pyrogallol-sodium phosphate wash solution in a stream of nitrogen and determined spectrophotometrically by the conversion of p-amino dimethylaniline sulphate to methylene blue. Except for those containing abnormally large amounts of nitrate, samples require no pre-treatment. According to Freney (1958) a wide range of organic substances containing sulphur does not interfere, although certain inorganic sulphur compounds could, if present, be estimated as sulphate. Selenium is stated to interfere with the normal reduction method (quoted by Freney 1958). However, our own experience showed that the addition of 20 μg of selenium to samples caused no interference.

The method appeared to be applicable to a wide range of biological materials and sufficiently sensitive to determine accurately 1 to 300 μg of sulphate sulphur in 10-20 mg of dried pasture, or 1 ml of blood. With certain modifications the methylene blue method has been adapted to routine use in this laboratory. Some applications of the technique have been described elsewhere (Cunningham and Hogan 1959a, b). Details of the modifications made in this laboratory are discussed below.

The Reducing Mixture

Several reducing mixtures using either red phosphorus (St. Lorant 1929; Johnson and Nishita 1952) or hypophosphorus acid (Johnson and Arkley pers. comm. Bergthe 1956; Roth 1951; Archer 1956), for the conversion of sulphate to hydrogen sulphide have been described. We have used both these forms of phosphorus successfully. However, the mixture containing red phosphorus is a suspension and difficult to prepare and dispense. We modified the preparation of the mixture slightly by fitting a condenser to the boiling flask during heating. This prevents the mixture from becoming a paste and makes it easier to dispense. This more dilute mixture was found to be satisfactory. We were unable to regenerate this mixture after use, as described by Johnson and Nishita (1952), but if the phosphorus is filtered off and the liquid fractionated, hydrogen iodide can be recovered and used again. On one occasion the red phosphorus failed to give satisfactory results. This was from a batch subsequently found to contain phosphide.

A hypophosphorus acid mixture has been described by Johnson and Arkley (pers. comm.) as follows:

"Mix 300 ml hydriodic acid (S.G. 1.7, Methoxyl grade), 75 ml hypophosphorus acid (50%) and 150 ml 90% formic acid. Boil, with

a stream of nitrogen flowing through the solution for about 10 minutes (gently) after the temperature of the solution has reached 115°c. Ordinarily the reagent is discarded and not regenerated because of the hazard of evolution of poisonous phosphine at temperatures above 120–125°c."

We prefer this mixture to the one containing red phosphorus since as a liquid it is easier to prepare and dispense. Samples analysed using both mixtures have given comparable results.

The Apparatus

Some of the precautions recommended by Johnson and Nishita (1952) have been omitted in this laboratory without loss of accuracy. It was found that nitrogen could be used without first bubbling it through a wash solution to eliminate possible traces of sulphur gases.

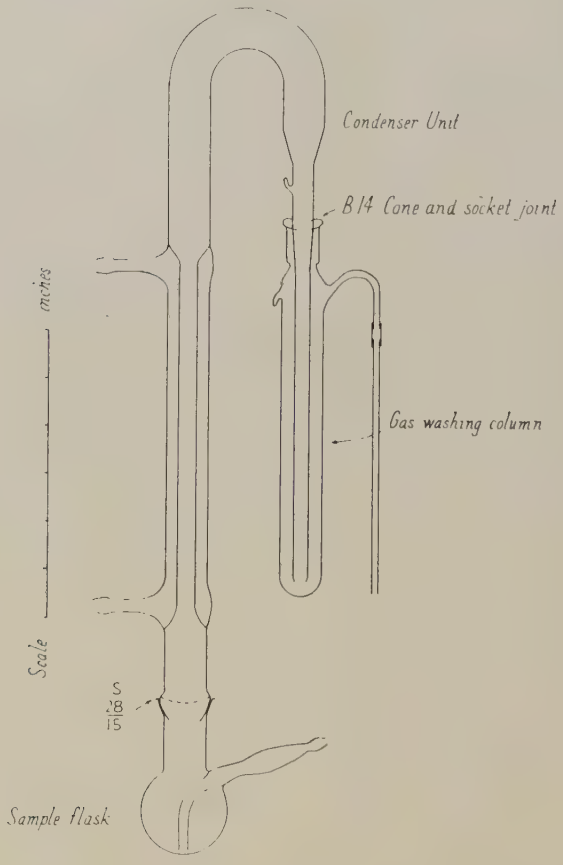

Fig. 1.—Modified digestion distillation unit.

Our attempts to remove any sulphur compounds from Dow Corning Silicone stop-cock grease were not successful as the grease became tacky and lost its value as a lubricant. The lubricant was used without purification and did not increase the blanks.

The unit shown in Fig. 1 is an idealised version of that used at Wallaceville and can be compared with Fig. 1 in Johnson and Nishita's (1952) paper. The joint above the condenser has been eliminated and that joining the delivery tube from the condenser unit and the gas washing column has been simplified. Polythene is used to connect the delivery tube to the gas-washing column where it enters the volumetric flask.

In our hands the side arm and tap attached to the lower end of the gas-washing column have not been found essential and are eliminated.

A battery of 6 units is shown in Fig. 2. In these the taps attached to the lower end of the gas-washing column have been sealed off with "Apiezon" wax as they were found unnecessary. The units are set up on a "Lablox" frame secured to a wooden stand so that the set can be moved as a unit. The condenser units are attached to a board and the board attached firmly to the frame with Terry clips. The whole apparatus occupies 7 feet of bench space on which the entire analysis can be carried out, except the weighings and spectrophotometric readings.

After repeated use the condenser unit becomes clouded with hydrogen iodide. If this is left in the apparatus free iodine is liberated which oxidises hydrogen sulphide giving low results. This source of

Fig. 2.—A battery of fixed units in operation.

error is removed by daily washing of the apparatus. When the gas-washing columns are removed for recharging with pyrogallol the condenser units can be washed out *in situ*. This is done by placing a beaker of distilled water under the condenser unit in place of the sample flask. The other end of the condenser unit is attached to a filter pump and the water drawn through the apparatus. A CC 1/28 Quickfit joint is then attached to the tube from the pump. A beaker of water is placed under the delivery end of the condenser unit and with the Quickfit joint attached in place of the sample flask, the water is drawn through the apparatus. Using this technique the 6 units can be washed thoroughly in about 5 minutes. The sample flask and gas-washing column are rinsed out with distilled water.

Efficiency

The precision of the results obtained by one worker using this technique was tested by evaluating the results obtained in 18 repeated determinations on a pasture sample according to the formulae given in Lundell and Hoffman (1954). The figures obtained are given below:

	Sulphate Sulphur (gm%)
Arithmetical mean	.109
Average deviation from mean	.0058
Probable error of a single determination	.0047
Probable error of the mean	.0011

The modified method has been used at Wallaceville for more than 3 years during which time approximately 3000 determinations have been made in duplicate. With experience, one worker can carry out 5 runs per day, that is about 75 duplicate analyses per week.

ACKNOWLEDGMENT

Our thanks are due to Messrs Hensen and Judd of the Department of Scientific and Industrial Research who made the glass portion of the apparatus including the spherical joints which have proved thoroughly reliable, to Mrs R. Freitag for translations of papers by Roth and St. Lorant, to Mr A. Bryant for the illustrations and to Miss E. Flett who carried out a large number of the analyses.

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STAPLE STRENGTH

I. THE MEASUREMENT OF STAPLE STRENGTH

By D. A. Ross, New Zealand Wool Industries Research Institute (Inc.), Dunedin

(*Received for publication, 14 March 1960*)

Summary

The incidence and importance of "break" in the New Zealand wool clip is discussed. A method is given for the measurement of staple strength, and some results of staple strength measurements on Romney and Corriedale wools are given and discussed. A correlation of 0.65 was found between staple strength and a hand assessment of strength on 721 samples of Romney Crossbred wool. There is wide variation in the staple strengths of wools which are all assessed by hand grading as being sound.

Introduction

The major fault in New Zealand wool is the high incidence of tenderness or break; that is, a region in the staple which has a low tensile strength. The term "break" is used in this paper to cover all degrees of this fault from a slight tenderness to a region in which there is almost a complete cessation of fibre growth.

Henderson (1955) reported the results of a survey of New Zealand wools in which 77,409 fleeces were examined and graded for wool faults. The incidence of break varied between different breeds, being 38% in Romneys and Crossbreds, 48% in Threequarterbreds and 50% in Corriedales and Halfbreds. Associated with this break were the other wool faults of cotting, yolk stain, cakey yolk, pink rot and dingy wool. Some of these secondary faults such as cotting and cakey yolk may result directly from the formation of a break. Eliminating break would therefore reduce or eliminate these associated wool faults. Henderson also found that fleece weight decreased with increasing severity of the break within the fleeces of one quality count group in a flock.

Another measure of the incidence and economic importance of wool faults and consequently of break, can be obtained from the statistics of the New Zealand wool clip published annually by the New Zealand Wool Commission. With the exception of a small amount of carbonising wool and combing and clothing oddments, the greasy fleece wool sold at auction is broadly classified into three style grades, namely—

(1) A and BB wool. Spinners and super topmaking wools, free from serious faults.

(2) B wool. Good/average topmaking wools, which have been down-graded for one or more faults.

(3) C and D wool. Average/inferior topmaking wools which have serious faults.

The Wool Commission's style grading data for the 5 seasons 1953-54 to 1957-58 have been sub-divided into 5 groups: (1) Merino (Mer), 60s and up; (2) Halfbred (½ Bd), 58/60s, 58s, 56/58s, 56s, 50/56s; (3) Fine Crossbred (F XBd), 52s, 50s; (4) Medium Crossbred (M XBd), 48/50s, 46/50s, 48s; (5) Strong Crossbred (S XBd), 46/48s, 46s, and lower.

TABLE 1. STYLE GRADINGS, YIELDS AND PRICES OF FLEECE WOOL SOLD AT N.Z. AUCTIONS FOR SEASONS 1953-54 TO 1957-58
(3,275,091 bales)

	Group	Style Grading			(A & BB) — (C & D)
		A & BB	B	C & D	
No. of bales as %	Mer	0.8	1.6	0.6	—
	½ Bd	2.9	13.2	5.7	—
	F XBd	2.6	16.1	5.1	—
	M XBd	2.4	22.0	14.5	—
	S XBd	1.0	7.6	3.9	—
	Total	9.7	60.5	29.8	—
No. of bales of each style in each group as %	Mer	28	52	20	—
	½ Bd	13	60	27	—
	F XBd	11	68	21	—
	M XBd	6	57	37	—
	S XBd	8	61	31	—
Yield %	Mer	64.4	62.1	57.7	6.7
	½ Bd	73.3	71.8	67.5	5.8
	F XBd	77.9	75.6	73.1	4.8
	M XBd	79.0	76.6	74.5	4.5
	S XBd	79.4	77.0	75.3	4.1
	Clip Mean	75.8	75.0	72.7	3.1
Price d./lb	Mer	67.5	61.8	54.1	13.4
	½ Bd	64.4	59.0	53.5	10.9
	F XBd	56.4	53.0	49.3	7.1
	M XBd	54.9	50.7	47.8	7.1
	S XBd	55.0	50.4	48.0	7.0
	Clip Mean	59.2	53.3	49.3	9.9
Price d./lb allowing for differences in yield	Mer	65.3	61.8	58.6	6.7
	½ Bd	63.2	59.0	57.1	6.1
	F XBd	54.7	53.0	51.0	3.7
	M XBd	53.2	50.7	49.1	4.1
	S XBd	53.5	50.4	49.1	4.4
	Clip Mean	57.6	53.4	51.2	6.4

It can be seen from Table 1 that only 10% of the fleece wool was classified as A and BB, that is wool free from serious faults, while 30%

was classified as inferior C and D wools, full of break, cotts, seed, colour and bush stain. Some 90% of the clip therefore has been down-graded and a very high proportion of this wool would have shown some degree of tenderness. Only 3% of the clip was classified as Merino wool of 60s count or finer while 75% was classed as Crossbred wool of 52s count or stronger. It may be seen from Table 1 that the proportion of the Merino wool graded as being of A and BB style was high, at 28%, and that the proportion decreased to only 6% and 8% for the medium and strong Crossbred wools respectively. Conversely the proportion of C and D wool was higher for the Crossbred than for the finer wools.

With decreasing style there was a decrease in yield. Between the A and BB, and the C and D wools, there was a decrease of about 6% in yield for the fine wools and 4% for the Crossbred wools. The difference as shown by the weighted means was however only 3.1% for the whole wool clip. This is due to the comparatively high proportion of low-yielding A and BB Merino wool.

With decreasing style there was also a decrease in price, the difference in value between A and BB, and C and D wool being about 12d for the fine wool and 7d for the Crossbred. There was a larger drop in value for the medium and strong Crossbred wool between A and BB, and the B wool than between the B, and the C and D wool. Also shown in Table 1 are the calculated prices of the wools based on the price of the B style wools, making allowance for the differences in yield. It is apparent that a considerable proportion of this "premium for style" is in fact due to the associated higher yield of the better style wool. The difference in value on this basis between the A and BB, and the C and D wools is thus about 6d for the fine wools and 4d for the Crossbred wools. Again the mean weighted price for the A and BB style wools is considerably affected by the relatively high proportion of high priced Merino wool in this group.

This relatively low financial premium for an improvement in style, when allowance is made for differences in yield, emphasis the comparatively small financial incentive offered to farmers to induce them to improve the style of their clips. Nevertheless a small difference in the price per pound amounts to a large sum over the whole clip. Other things being equal, it can be calculated, using a mean bale weight of 338 lb, that if the B and the C and D grade wools were improved to A and BB style, the growers would have received another £23m, over the 5 seasons. Of this amount, £14m would be attributable to the improvement in style and £9m to the accompanying increase in yield.

The 3,275,091 bales of fleece wool included in this analysis represent only 64.3% of the total quantity of greasy wool sold at auction in these 5 seasons. Any improvement in the style of the fleece wool would be accompanied by an improvement in the style and value of the combing and clothing oddments, so that a loss of at least £6m per annum may be attributed to the poor style of the greater part of the clip.

Table 2 shows the percentage of each style of wool sold at each auction centre. There is practically no A and BB style wool sold at

TABLE 2. Style Gradings of Fleece Wool 1953-54 to 1957-58 Seasons

Centre	Style Grading %		
	A & BB	B	C & D
Auckland	0.2	44.8	55.0
Napier	13.0	66.3	20.8
Wanganui	0.2	39.0	60.8
Wellington	10.7	58.7	30.5
Christchurch	11.8	62.9	25.3
Timaru	10.4	69.8	19.8
Dunedin	16.1	67.7	16.2
Invercargill	12.5	73.6	13.9

Auckland and Wanganui while 55% and 61% respectively of the wool sold at these centres is of C and D style. As the principal reason for the large quantity of poor-style wool is the high incidence of break and its associated faults a determined effort is required, particularly in the Auckland and Wanganui districts, to improve the general standard of the clip. However in view of the data presented in Table 1 on the relation between style, price, and yield, further detailed investigations are required on the economics of wool production, preparation for marketing, and methods of marketing, to form a sound basis for a wool improvement programme.

A marked seasonal rhythm of wool production in wool weight, diameter, and length was found by Story and Ross (1960) in full-mouth Romney Crossbred ewes run on the Taieri plain. The 10 ewes had a mean maximum fibre diameter in February of 42 μ and a minimum in August of 28 μ. This occurred even though the quantity of feed available in the winter was adequate although no measure was made of its quality. A similar seasonal rhythm of wool production was found by Hart (1955) in Corriedale ewes fed on a constant ration. While there is, therefore, normally a marked reduction in fibre diameter in the winter-early spring period, this in itself does not result in the formation of a break. At the same time there is a further thinning down and/or shedding of some fibres due to the effect of such factors as nutrition, parasites and diseases, management, pregnancy and lactation, age, sex, and heredity. While a break may be induced at any time of the year by such factors as illness or a very low level of nutrition, this series of papers is primarily concerned with the "lambing break", that is, the break which occurs in the late winter-early spring period. The fact that dry ewes, wethers, and rams may also form a break at this time while on abundant feed indicates that the "lambing break" is not entirely nutritional in origin, nor the result of metabolic disturbances resulting from pregnancy and lactation. The hereditary aspects of break may be associated with fleece shedding which occurs naturally in the spring in some breeds of sheep.

The morphology of the changes which accompany the formation of a break has not been studied in New Zealand wools. Lang (1946),

in a study of tender Merino staples, found that particularly in those staples in which there was a marked difference in diameter between the coarse and the fine fibres, the coarse group may undergo little change while the fine fibres are markedly reduced in diameter. In wools with a normal type of fibre-diameter frequency distribution, all fibres were reduced similar amounts in cross-section. Of the fibres which ended at the break, 97% had normal root bulbs, the other 3% tapered to a blunt end without a terminal bulb. The diameter of the fibre at which it was shed was less than 14 μ in Merinos, the majority being 8 μ. The diameter at shedding was greater in the coarser types of wool.

The two major factors determining the uses and performance during manufacture of a wool are its fibre diameter and fibre length. Fibre length at different stages of processing is dependent on the original staple and fibre length and the amount of fibre breakage that has occurred during processing up to any particular stage. The lower the strength of the wool before processing the greater will be the fibre breakage during processing and the lower will be the mean fibre length of the processed wool. As a result of this fibre breakage more noil will be produced and a lower tear obtained. The drawing and spinning of the wool will be less satisfactory and a weaker yarn, more likely to break in weaving, will be produced. Finally it would be expected that the strength of the final cloth would be lower than similar cloth with a higher mean fibre length.

Another aspect of break which is of considerable importance is the position in the staple where the break occurs. Where the break is close to the butt of the staple the short fibre broken off during carding will be removed in the noil. If on the other hand the break is near the centre of the staple the majority of the broken fibres may be of sufficient length to pass into the comb sliver, resulting in a top with a very low mean fibre length but produced with a reasonable tear.

The method used in the wool trade to measure the soundness of a staple is to stretch the staple and flick it with a finger. The soundness is estimated from the "ring" of the staple or the pull required to rupture it. By this method staples are classified into only two groups, sound and unsound, although there are all degrees of soundness from unbreakable staples to staples in which there is a region where most of the fibres have ceased growing and which need only the lightest pull to break them. Using this method Pohle *et al.* (1958) found some divergence of opinion on whether certain lots of wool were sound, and pointed out the need for a more objective method of measuring soundness. In the survey reported by Henderson (1955) 6 grades were used to describe staple strength. While this system gave some measure of the degree of soundness, changing standards are inherent in such a subjective grading system, due to differences between assessors, and at different times for individual assessors. The size of the staple will affect the judgment of the degree of break, thin staples tending to be down-graded and thick staples up-graded. As break is such an important fault in New Zealand wool, any long-term research programme which has as its ultimate aim the elimination of break from New Zealand wools must be based on an unchanging objective method of measuring staple strength.

The measurement of the stress-strain curves of individual wool fibres has for long been accepted as a very useful technique in textile research. The sensitive mechano-chemical methods of single fibre analysis developed by Speakman (1947) have been widely used to detect changes in fibres after physical and chemical treatments. From such tests data on the structure of the wool fibre itself have been deduced.

There has been an extension of single-fibre testing to the measurement of the strength of flat bundles of fibres in which the fibres are made parallel and evenly tensioned before force is applied to the bundle. This technique has found wider application with cotton than with wool and the American Society for Testing Materials give specifications for testing fibre bundles of wool (D 1294-53T), cotton (D 1445-53T), and rayon and acetate fibres (D 540-44). All three tests, however, are carried out with what is essentially zero distance between the jaws clamping the fibre bundles. Gonsalves (1947) working with cotton and rayon staple fibre found that the flat-bundle method gave a strength of about 60–70% of the strength as calculated from the total of the strengths of the individual fibres. As discussed by Patt and Stock (1957) the maximum strength of fibre arrays compared with the sum of the strengths of the individual fibres is always noticeably lower, and the maximum elongation higher, owing to differences in the length and tautness of fibres in the bundle or tow at the start of the test.

Method for the Measurement of Staple Strength

General Considerations

The measurement and interpretation of the results of tensile strength tests on greasy-wool staples introduces many problems that are not found in testing individual wool fibres, fibre bundles, yarns, or strips of cloth. The lengths of fibres held between two clamps on a staple will be highly variable. In general many of the shorter fibres, which will also be the finest diametered, will have ruptured when the longest, coarsest fibres between the clamps are only slightly extended. The finer shorter fibres will, however, be of secondary follicle origin and Burley and Speakman (1953) found that such fibres have a higher plasticity than the longer coarser fibres of primary-follicle origin. Staples with the same total single-fibre strengths could sustain different maximum loads depending on the relationship of fibre length and strength within each staple although the total amount of work required to break the staples would be similar.

If breaking stress is independent of fibre diameter along a single wool fibre, then the major factor determining the force required to rupture a staple would be the total of the minimum cross-sectional areas of the fibres which are held in both clamps. In most staples of post-lamb-shorn wool, the weakest region of the "lambing-break" will be about the level where the fibre diameter is at its seasonal minimum (Story and Ross 1960). As this region of low tensile strength is usually 1–2 inches above the butt in Romney wool staples, it must be placed between the clamps if the minimum staple strength is to be measured. While a low staple strength would show that there was a region of low

tensile strength in the staple, it would not imply that the wool fibres, above and below this weak region, are of low intrinsic strength. While weathering markedly reduces the strength of wool fibres (McMahon and Speakman 1937), it would not be expected to affect the butt region of the staple where the break normally occurs.

Other things being equal the breaking load of a staple will vary with the size of the staple and the distance apart of the clamps. As the sizes of staples, even of one quality number, are very variable, the only practical basis for comparing the staple strengths of different samples would appear to be the strength per unit weight of fibre cut from between the clamps after breaking the staple at a specified test length. As staples also vary widely in their grease, suint, dirt, and moisture contents, they would need to be cleaned and then brought to a similar moisture content to give a comparable weight basis for between-sample comparisons.

Assuming that the weakest part of the staple is between the clamps, then the breaking load (lb) would be approximately constant irrespective of test length, but the breaking load expressed in lb/g would increase rapidly as the test length decreased and consequently the wool weight between the clamps decreased.

To ensure that the minimum staple strength is measured, i.e., that the break is between the clamps, it would be necessary to have as long a length of the staple as possible between the clamps. This distance will depend on the length of the staple, the width of the clamps, the desirability of clamping all the fibres in both jaws and therefore the length of the shortest fibres in the staple, and the avoidance of the tip region which may have been weakened by weathering. In any tests on groups of wool samples, a principal factor determining the test length will be the length of the shortest staple.

While breaking fibre bundles with essentially zero jaw separation is a standard test procedure, there are no data available on the accuracy of strength tests with greater than zero jaw separation. Trials were carried out on the repeatability of strength tests on bundles of wool and synthetic fibres and on wool and synthetic fibre tops. The results of these trials have been reported elsewhere (Ross 1960). With bundles of synthetic fibres at a test length of 2.0 in., the coefficients of variation within groups of repeat strength tests were very low, varying from 1.4% to 3.6%. For repeatability trials with wool fibre bundles and wool tops, coefficients of variation of the order of 4%–7% were obtained.

Testing Procedure

Strength Tester. The strength tester available was a "Goodbrand" yarn (hank) strength tester with a load capacity of 200 lb. This machine is a pendulum dead weight type tester in which the material to be tested is held in jaws suspended by a steel tape from a pulley to which is fixed a weighted lever. The other end of the material is pulled by a jaw moving at a constant rate of 3.8 inches per minute.

As the upper jaw moves to allow the quadrant to register the load, there is neither a constant rate of extension, nor of loading of the

specimen. The rate of loading therefore depends upon the rate of traverse of the pulling jaw, the movement of the top jaw necessary to register the load, the extensibility of the specimen just before it breaks, the length of the specimen being broken and the characteristics of the particular machine which is used (Onions 1956). This type of tester is not accurate over the lower 10% of its range. A device to record traverse and force was fitted to the tester, and had a limit of 120 lb. The ratchet preventing return of the pendulum was made inoperative.

Clamps. The metal clamps for gripping the staples had a working distance between the clamping bolts of 1.8 in. The front 0.1 in. of the clamps was flat while the back 0.9 in. was deeply serrated. Both clamps of each pair were leather lined.

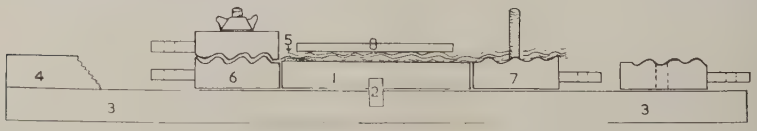

Fig. 1.—Holding jig. 1. Spacing block. 2. Peg to hold (1). 3. Base of jig. 4. Guide rails. 5. Staple of wool. 6 and 7. Holding clamps. 8. Lead weight.

Holding Jig. Fig. 1 illustrates a wooden jig which was constructed to hold the clamps while preparing a staple for testing. Interchangeable wooden blocks (1) were made of various lengths to give any desired jaw separation distance. The spacing blocks were fitted over a peg (2) in the base of the jig (3) to hold them firmly in place between the guide rails (4).

Testing Method. All staple-strength testing and wool conditioning was carried out in a room maintained at 68°F. and 65% r.h., and all wool was conditioned for at least 24 hours before testing. A staple (5) was laid without stretching across the clamps (6 and 7) which had been placed against the spacing block. The butt 0.75 in. was clamped in one jaw and when necessary the staple was straightened and a lead block (8) smaller than the spacing block was placed on it. The tip of the staple was cut off to avoid blocking the fastening hole in the clamp and the second clamp was then tightened. The clamps were fastened by pins to slotted brass straps which fitted on to the strength tester hooks.

After the staples had been completely broken on the strength tester the broken fibres were cut from the clamps and the two pieces were placed in a long handled metal tea infuser (spoon type). The wool in the infuser was degreased in three changes of petroleum ether, then agitated in water at about 130°F. to remove the residual ether and the water-soluble suint. The tea infusers were next hung on a hand centrifuge and spun to remove excess water, the cleaned wool pieces being then placed in numbered trays, oven-dried to a low regain, conditioned for at least 24 hours, and finally weighed.

Up to 4 breaking-load graphs were recorded on a conditioned and weighed sheet of foolscap paper. The breaking load graphs were cut

from the sheets and weighed to find the areas enclosed. It was found necessary to weigh each sheet of foolscap because of large variations in weight between sheets from the same packet, while variations in weight within a sheet were small.

Breaking Graphs

It is not proposed at this stage to discuss any of the numerous factors which affect the measurement of staple strength, but to illustrate the types of breaking graphs which have normally been recorded. While the breaking graphs of sound staples show little variation in shape, as the staple strength decreases a much wider variety of breaking graphs is recorded.

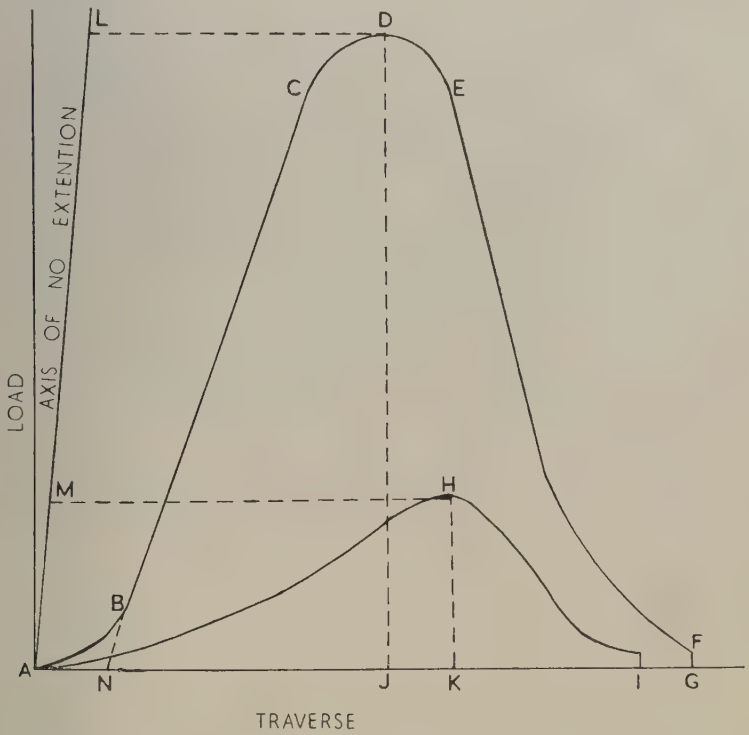

Fig. 2.—Staple strength graphs of a sound and a tender staple at a test length of 2.5 in. Lettering explained in text.

Fig. 2 shows the breaking graph of a sound staple ADG, and a fairly tender staple AHI, where the test length between the jaws was 2.5 in. On this type of tester the axis of no extension lies at an angle to the ordinate (5° in this case) because of the movement of the upper jaw which is necessary to register the load. As the load on the sound staple is increased there is an initial uncrimping region AB when fibres

and the staple are being straightened and the shortest fibres come under appreciable load. The staple extends considerably in this region, which is longer the weaker the staple. With increasing load there is a region BC in which the load increases at a constant rate with traverse and a small amount of staple extension occurs. As the maximum load D which the staple will sustain is approached some fibres will be breaking while the rest come under increasing load. There is considerable staple extension with little increase in total load over the region CE about the point of maximum load.

After the maximum load is reached the staple does not normally break suddenly (although this may happen with short test lengths of sound staples) but decreases gradually as the longer fibres in the staple are fully loaded, extended, and broken. The staple breaks completely at the point F and FG represents the weight of the bottom clamp and brass strap which drop down when the staple breaks. The traverse line GA obtained on reversing the tester returns to slightly below the starting point as the staple is initially placed on the tester with the two clamps and brass straps, each unit weighing about 1 lb. At the starting-point the staple is thus actually under a load of approx. 1 lb.

In the case of weaker staples the initial uncrimping region is longer and there is no clearly defined demarcation between this region and the main staple loading region. Such staples frequently have a greater extension at maximum load than sound staples but a smaller extension at the final staple break point.

The following are the principal parameters which may be derived from the breaking graphs and the clean conditioned weight of the wool cut from the clamps after breaking. Usually only a few of these parameters would be calculated, depending upon the aim of the experiment. Where maximum load alone is required this may be read directly from the dial of the strength tester.

Maximum Load. In textile testing the terms maximum load and breaking load are usually used as synonyms. As applied to wool staples, however, the term breaking load is rather ambiguous. Unless the test length is very short the staple does not break completely until the load has almost returned to zero. The proportion of the fibres in the staple which will be broken when the maximum load is reached will depend upon many factors which will vary from staple to staple. The maximum loads of the sound and the weak staples illustrated in Fig. 2 will be proportional to DJ and HK respectively. From the clean weight of the wool cut from the clamps after breaking, the maximum load may then be expressed in lb/g of clean conditioned wool at a given test length.

Work. It can be seen from Fig. 2 that the amount of work performed in reaching the maximum load may only be about half of that required to completely break the staple, although in general it is the latter which is of interest. This was obtained from the area of the breaking graph (i.e. ADG and AHI) by relating its weight to the weight and area of the foolscap sheet. Work was measured in cm lb and knowing the weight of wool it could be expressed as cm lb/g of clean conditioned wool at a given test length.

Traverse, Extension at Staple Break, Breaking Time. The traverse or extension of the sample at staple break (i.e. AG and AI) depends on the length, strength, and extensibility of the longest fibres between the clamps. As the tester is a constant-rate-of-traverse machine, the traverse is directly related to the breaking time.

Extension at Maximum Load. This was obtained by measuring the distance from the point of maximum load to the axis of no extension, i.e. DL and HM respectively, for the sound and weak staple. In the case of many weak staples the maximum load was constant during a few cm traverse and in these cases the extension was measured from the mid-point of this region to the axis of no extension.

Breaking Angle ϕ. The initial uncrimping region in the sound staples ADG is followed by a region where load increases in direct proportion to traverse BC. If CB is extrapolated it meets the traverse axis at N. Then the angle CNG(ϕ) will have a value depending on the strength and extensibility of the staple.

Discussion of the Results of Some Staple-strength Tests

The heterogeneity of the fibres in a staple and the wide variation in staple formation both within and between fleeces, together with variations in testing technique, result in many factors which will affect the measurement and the interpretation of staple strength tests. Some of these factors will be discussed in later papers in this series. It is proposed at this juncture to present the results of some staple strength tests on Romney and Corriedale wool so as to give an indication of the type and level of results which may be expected.

Trials have been carried out over a number of seasons of the effect on the wool production of Romney and Corriedale ewes, of shearing either before or after lambing (Story and Ross 1959). The staple strength was measured of one staple from the side of each ewe in the 1955 and 1956 seasons. In both breeds the butt 0.75 in. was clamped and the staples were broken with a test length of 2.5 in. for the Romney and 1.5 in. for the Corriedale samples. The mean values for the staple strength (maximum loads) of each group of ewes have been reported by Story and Ross (1959). A more comprehensive picture of these results is given in Table 3, where data on work, extension at maximum load and at staple break, as well as the weight of the staples tested and the variation of the various measurements in the groups are given.

These results are of particular value for illustrating staple-strength data, as they cover the range from very sound to very weak staples. They are discussed firstly as a comparison between groups of sound and weak wools of the two breeds and secondly on the basis of the variation within the groups and the interrelationships of the various strength measurements.

It may be seen from Table 3 that the pre-lamb-shorn staples were from two to two and a half times as strong as the corresponding post-lamb-shorn staples. Staple strengths similar to those of the pre-lamb-shorn samples would be expected if the post-lamb-shorn staples were

TABLE 3. STAPLE STRENGTH DATA ON PRE- AND POST-LAMB-SHORN ROMNEY AND CORRIEDALE WOOLS
(Test length: Romney wool 2.5 in.; Corriedale wool 1.5 in.)

Year	Type	No.		ML[1] lb/g	W[2] cm lb/g	EML[3] %	ESB[4] %	SW[5] g
1955	R.Pre-L.[6]	151	m[10]	162	603	43	115	0.41
			v[11]	23	21	18	14	30.8
	R.Post-L.[7]	98	m	61	255	53	116	0.46
			v	53	51	37	20	31.7
1956	R.Pre-L.	133	m	142	562	46	122	0.49
			v	27	25	18	16	32.0
	R.Post-L.	106	m	58	274	61	124	0.29
			v	51	42	32	17	27.8
1955	C.Pre-L.[8]	93	m	238	592	51	128	0.19
			v	18	19	19	16	30.8
	C.Post-L.[9]	95	m	113	298	53	121	0.18
			v	48	44	31	23	38.4
1956	C.Pre-L.	96	m	228	631	57	144	0.21
			v	19	18	18	18	19.1
	C.Post-L.	80	m	117	395	70	157	0.19
			v	49	40	26	18	35.8

[1] Maximum load
[2] Work
[3] Extension at maximum load
[4] Extension at staple break
[5] Sample weight
[6] Romney pre-lamb-shorn
[7] Romney post-lamb-shorn
[8] Corriedale pre-lamb-shorn
[9] Corriedale post-lamb-shorn
[10] Mean
[11] Coefficient of variation %

broken with the test length between the jaws representing the same growing period as with the pre-lamb-shorn samples. Because of the marked seasonal variations in fibre diameter, the mean cross-sectional area of the test length of post-lamb-shorn staples will be smaller than that of the pre-lamb-shorn staples. On the basis of the seasonal fibre diameter measurements given by Story and Ross (1960) for Romney ewes, the minimum cross-sectional area in the test length, and consequently the actual breaking loads of the pre- and post-lamb-shorn Romney groups would be in the ratio of approx. 1.5 to 1. However, as the region under test of the post-lamb-shorn samples is finer, the same number of fibres will weigh less so that the maximum load in lb/g of the post-lamb samples would be partially compensated for by the lower cross-sectional area, depending on the relation between this area and the mass of the fibres in the given test length.

No comparisons of maximum load may be made between the breeds without taking into account the differences in test length. On the basis of breaking a similar cross-section of fibre (maximum load x test length) the pre-lamb-shorn Romney staples were stronger than the pre-lamb-shorn Corriedale staples, and vice-versa for the post-lamb-shorn staples. Such comparisons, however, do not take into account the decrease in strength which is found with increasing test length of even the most uniform fibre bundles (Ross 1960).

In general the average values for the various measurements are of a similar order for corresponding groups in the two seasons. The

only real exception is in the case of the 1956 post-lamb-shorn Corriedale wool in which the maximum load was similar to the previous year but the total amount of work to completely break the staples was much higher, due to the greater extension both at maximum load and at staple break of these samples.

In all cases the variation within a group as shown by the coefficients of variation in Table 3 was much higher for the post-lamb-shorn group than for the corresponding pre-lamb-shorn group. This increase in variation is no doubt largely due to the different response of the individual ewes to the stresses of pregnancy and lactation, at a time when the food supply may be poor, and wool production and fibre diameter reach a minimum.

Maximum Load. For Romney staples with a 2.5 in. test length, the maximum load values ranged from almost zero to over 200 lb/g. In some other tests on pre-lamb-shorn wools, maximum loads of up to 300 lb/g have been found. The highest maximum load at which Romney staples can be broken by hand is about 100 lb/g, so it is apparent that there is wide variation in the strengths of "sound" staples which cannot be detected by the hand assessment of break. With the shorter test length of the Corriedale samples, maximum load values of the order of 400 lb/g have been obtained.

The ratio of the maximum loads of the pre- and post-lamb-shorn groups were very similar in the two years, being 2.5 : 1 for the Romneys and 2.0 : 1 for the Corriedales.

Work. The work in cm lb/g and the maximum load in lb/g required to break a bundle of straight rayon fibres with a test length of 2.0 in. were of a similar order (Ross 1960). Wool fibres, however, are much more extensible than rayon fibres and, as they vary in length between the clamps, the amount of work required to break completely a wool staple, in cm lb/g, was much higher than the maximum load, in lb/g. The relation between work and maximum load will vary with the test length. It was approximately 3.8 and 2.6 : 1 for the Romney and Corriedale pre-lamb-shorn wools respectively, and 4.5 and 3.0 : 1 for the post-lamb-shorn wools, the higher ratio with the post-lamb-shorn wools being due to the greater extension at both maximum load and staple break of these samples.

Values for the amount of work required to break completely a staple ranged up to about 1000 cm lb/g and were of a similar order for both breeds, although there were differences in test length. With bundles of uniform fibres such as rayon, the work in cm lb/g required to break the bundle decreases at a slower rate than maximum load in lb/g as the test length increases, owing to increases in extension of the bundle with increasing test length.

Extension. As the fibres between the clamps vary in length, the extension of the staple at break would be higher than the breaking extension of a staple of straight fibres. The percentage extension at staple break was very similar for each of the corresponding groups of

pre- and post-lamb-shorn wools. The percentage extension was also similar as between the Romney and the 1955 Corriedale samples. The 1956 Corriedale samples, however, which were from the same ewes as the 1955 samples, had a higher extension at both maximum load and staple break. This may have been due to differences in feed between the years as well as to the difference in age.

The region of the staple broken in the pre-lamb-shorn group corresponds to a region 1 to 2 inches higher up the staple in the post-lamb-shorn group, this being the length of wool grown from the time of the pre- to the post-lamb shearing. The mean diameter of the fibres between the clamps will be lower for the post-lamb-shorn group than for the pre-lamb-shorn group. The extension at staple break will depend upon the strength and extensibility of the longest and coarsest fibres. Anderson and Cox (1950) found that there was a tendency for the thicker fibres in a Romney staple to break at higher extensions. Now the extension at staple break of the weak post-lamb-shorn staples was as large as the extension of the strong pre-lamb-shorn staples in the corresponding groups. The large fibres governing the extension at staple break, which would be largely of primary follicle origin, would therefore appear to be unaffected by the factors which have reduced the strength of the shorter finer fibres of secondary follicle origin in the post-lamb-shorn staples. The fact that in all cases the extension at maximum load of the post-lamb-shorn samples was higher than the corresponding pre-lamb-shorn samples also indicates that the shorter finer fibres of secondary follicle origin have been more reduced in strength by the factors causing the "lambing break".

The hypothesis advanced for the similar extensions at staple break of the corresponding groups implies that the ratio of fibre length to test length in the groups is similar. This may not be so, however. If the longer coarser fibres are not as much affected by the factors causing the lambing break as the shorter finer fibres, and if the rate of growth of the finer fibres relative to the longer fibres is slower during the break-forming period, the finer fibres may reduce the rate of increase in staple length. As a result of this the ratio of the length of the longest fibres to the test length may be as high (or higher) in the post-lamb samples as in the pre-lamb samples.

There are changes in the weight, diameter, and length of wool grown by a sheep during the year. There are also changes in the chemical composition of fibres throughout the year. Differences in staple strength between the corresponding pre- and post-lamb-shorn sheep may in part be due to changes in the composition of fibres as well as to changes in cross-sectional areas of the fibres. While the longer fibres of the post-lamb-shorn samples between the jaws are probably slightly finer than the pre-lamb-shorn fibres they may be more extensible.

With increasing breaking time the breaking load of fibre bundles decreases (Ross 1960). As the extension at staple break for the corresponding groups was similar, the traverse and consequently the time to break the staples were also similar.

Sample Weight

While the results of maximum load and work measurements are expressed per unit of weight at a given test length, this does not preclude the possibility that the staple size affects maximum load, work, and extension at maximum load or staple break. As shown in Table 3 the mean sample weights for the Romneys were similar for all but the 1956 post-lamb-shorn samples which were lighter, while the mean sample weights were almost identical for the 4 Corriedale groups.

TABLE 4. Sample Correlations

Year	Type	Correlation Coefficients				
		Sample Weight and				ML and ESB
		ML[1]	W[2]	EML[3]	ESB[4]	
1955	R.PreL.[5]	—0.055	—0.082	—0.183*	0.204*	—0.239**
	R.Post-L.[6]	—0.134	—0.177	—0.120	0.100	—0.315**
1956	R.Pre-L.	—0.222*	—0.157	0.034	0.360**	—0.270**
	R.Post-L.	—0.025	—0.012	0.081	0.281**	—0.125
1955	C.Pre-L.[7]	—0.115	0.106	0.293**	0.502**	—0.181
	C.Post-L.[8]	0.224*	0.212*	—0.066	0.347**	—0.488**
1956	C.Pre-L.	0.162	0.124	—0.077	0.173	—0.129
	C.Post-L.	0.096	0.006	—0.055	0.309**	—0.023

* $P < 0.05$ ** $P < 0.01$

[1] Maximum load lb/g
[2] Work cm lb/g
[3] Extension at maximum load %
[4] Extension at staple break %
[5] Romney pre-lamb-shorn
[6] Romney post-lamb-shorn
[7] Corriedale pre-lamb-shorn
[8] Corriedale post-lamb-shorn

Table 4 shows the correlations between sample weight and maximum load, work, and extension at maximum load and at staple break for each group. Some of these correlations reach the 5% or 1% levels of significance. The correlations for some individual characteristics, such as maximum load and sample weight, vary from significantly negative to significantly positive for different groups of wools.

While only one correlation between sample weight and maximum load of work is significant at the 5% level for the groups of Romney wool, all were negative correlations. A negative correlation might be expected with the weaker post-lamb-shorn staples, as where a sample had an obvious break a larger staple was taken to avoid a low value on the strength tester and to prevent the staple being broken by the weight of the clamp and brass strap. However, this does not apply to the pre-lamb-shorn groups in which all the staples appeared to be sound. There was no consistency of these relationships between the Romney groups in succeeding years, the correlations being higher for the post-lamb-shorn group in 1955 and the pre-lamb-shorn group in 1956.

For the Corriedale groups the relationships between sample weight and maximum load or work were the opposite of those found with the Romneys. Seven of the 8 correlations were positive, that of the 1955 post-lamb-shorn samples being significant at the 5% level.

With the exception of the 1955 Romney and Corriedale pre-lamb-shorn wool groups, sample weight had little effect on the extension of the staple at maximum load. Again the one significant correlation was negative for the Romney group and the other was positive for the Corriedale group.

With increasing sample weight the extension at staple break for all groups increased. Table 3 shows that on the average the weaker post-lamb-shorn staples extended if anything slightly further than the sound pre-lamb-shorn staples, before the staples were completely broken. This comparison is, however, between sections of staples grown at different times under different conditions. If extension at staple break is dependent on the strength of the longest and coarsest fibres and if the strength of this group is independent of the general level of staple strengths and of the severity of the break, then as a result of the large variation in strength between fibres within a staple, with larger staples the possibility of getting longer and stronger fibres in the staple is increased and so extension at staple break would increase with sample size.

Also shown in Table 4 are the correlations between maximum load and extension at staple break. Even in those groups in which there was no significant correlation or a positive correlation between sample weight and maximum load, there was a reduction in extension at staple break as maximum load increased. As discussed previously, it appears that either there is a different crimped/straight length ratio, which increases as the severity of the break increases owing to holding back by the finer, slower growing, more retarded fibres, or the factors causing break result in an increase in fibre extensibility and/or the strength of the longer fibres.

The tester used for these measurements is not a sensitive apparatus and the number of unbroken fibres will decrease as the maximum staple extension is approached. As the weight of the lower clamp and brass strap is approximately 1 lb, the extension at staple break will be the extension of the staple when the number of fibres remaining will not carry a 1 lb load. Assuming staples with similar fibre length and strength distributions, a large staple with more fibres to support the clamp would have a slightly longer total extension, under these conditions, than a small staple.

The effect of sample weight was also studied on two groups of 10 staples taken from a small sample of pre- and post-lamb-shorn wool, with a test length of 2.5 in.

It can be seen from Table 5 that, for sound wool staples 1 to 10, there was a decrease in maximum load and work as sample weight increased. While sample weight had no effect on the extension at maximum load, the extension at staple break increased appreciably as the sample weight increased. However, with the weaker post-lamb-

TABLE 5. Effect of Sample Weight on Staple Strength
(Test length 2.5 in.)

Staple No.	Sample Weight g	Maximum Load lb/g	Work cm lb/g	Extension at Maximum Load %	Extension at Staple Break %
1	0.11	220	827	41	102
2	0.13	213	823	43	107
3	0.17	229	837	43	107
4	0.27	198	750	41	121
5	0.32	212	827	43	124
6	0.39	203	786	41	124
7	0.41	195	819	44	129
8	0.46	217	826	39	128
9	0.50	179	712	43	129
10	0.60	181	776	43	142
11	0.03	56	220	50	85
12	0.11	70	187	52	60
13	0.11	119	513	43	110
14	0.16	103	491	61	135
15	0.22	93	468	71	142
16	0.29	105	510	61	145
17	0.59	102	507	65	161
18	0.61	109	531	58	153
19	0.77	120	579	60	162
20	1.08	101	568	68	187

shorn wool, staples 11 to 20, with the exception of the 2 small staples 11 and 12, sample weight had little effect upon maximum load, but there was an increase in the work required to break the larger staples. There was no appreciable effect of sample weight on the extension at maximum load although the results were somewhat erratic, and as with the sound pre-lamb-shorn staples the extension at staple break increased with increasing sample weight.

Sample Weight and Breaking Angle. It was only possible to measure the breaking angle on the stronger pre-lamb-shorn samples, in which there was a clearly defined region where breaking load increased at a constant rate with traverse. The mean breaking angles for the 1955 and 1956 pre-lamb-shorn Romney samples were 74.0° and 74.7° respectively, with low coefficients of variations of 9.6% and 7.7%. With increasing sample weight there was an increase, significant at the 1% level, in the breaking angle in both groups.

The preceding results show that the importance of sample weight in the evaluation of staple strength data will depend upon many factors such as the parameter being measured, the general level of strength of the samples, the test length, and the characteristics of the particular wool being tested. In a comparison of groups of sound and tender wools, large staples of tender wool may be desirable in order to avoid the lower 10% of the range of the tester. Similar-sized staples of sound wool, however, may be too strong for the upper range of the tester. The use of a more sensitive type of tester in which the load is registered independently of jaw movement would overcome this problem.

It was found with wool tops (Ross 1960), that the breaking load at a given test length increased with both increasing sample weight, and with increasing sample compactness. With greasy wool the degree of fibre compaction is dependent on the fibre density of the staple, in a one- rather than in a two-dimensional form.

For post-lamb-shorn Romney wools, a sample weight of the order of 0.2–0.3 g/in. is most satisfactory.

Relationship of Maximum Load and Work

It will depend upon the aim of any particular experiment whether the breaking graph is required for which to calculate work, extension, etc. For many experiments only maximum load will be required and this may be calculated directly from the dial reading of the strength tester and the clean weight of the sample, without recording the breaking graphs.

TABLE 6. Correlations of Maximum Load and Work

Year	Type	Romney	Corriedale
1955	Pre-L.[1]	0.82	0.69
	Post-L.[2]	0.91	0.85
1956	Pre-L.	0.83	0.66
	Post-L.	0.90	0.84

[1] Pre-lamb-shorn
[2] Post-lamb-shorn

Table 6 shows the highly significant correlations that have been found between maximum load and work for the different groups of ewes. The correlations are higher for the weaker post-lamb-shorn groups than for the corresponding sounder pre-lamb-shorn groups. The correlations between similar groups for different years are almost identical indicating that the factors that control this relationship are characteristic of the group of sheep and the time of sampling.

The standard errors of the estimates for predicting work from maximum load are high, being from 12% to 14% of the corresponding means for the strong pre-lamb-shorn groups and from 19% to 27% for the weaker post-lamb-shorn groups.

Relationship of Maximum Load and Extension at Staple Break

In all groups, irrespective of sample weight, a high maximum load was associated with a low extension at staple break (Table 4). As within each group the wool between the jaws would be grown at approximately the same time, it might reasonably have been expected that the sounder staples would have the largest extension at staple break. Either the factors causing a reduction in staple strength increase the extensibility, particularly of the longer coarser fibres in the staple, or there is an increase in the fibre-length-test ratio as the staple strength decreases.

Uncrimping Extension

The extension of the sample over the "uncrimping" region before the load increases directly with the traverse can also be calculated for those sound staples in which the breaking angle can be measured. For the sound staple shown in Fig. 2 this uncrimping region is equivalent to the distance AN. As the staple is pre-tensioned by the weight of the clamp and brass strap this is not an uncrimping region in the sense in which this term is used in single-fibre load extension studies, nor is it equivalent to the "Hookean" region of a single-fibre load extension curve in which there is only a small initial extension of about 2–3%, for a comparatively large increase in load. The uncrimping region was on the average 3.5% and 4.6% of the test-lengths of the pre-lamb-shorn Romney and Corriedale wools respectively. This measure no doubt gives an estimate of the length of the shortest group of fibres in the staple in relation to the test length. Unless some problem of this type was being studied in sound wools, this measurement is of doubtful value as the uncrimping length represents only a small and relatively constant portion of the extension at either maximum load or staple break.

Staple Strength and Hand Assessment of Break

If the usual hand assessment of break is a useful guide to the quality and value of wool, then staple strengths and in particular the relationship between maximum load and the degree of break as assessed by hand measurement must be known.

Materials and Methods

A series of 721 small samples of wool was obtained from one flock of ewes, shorn on 23 January 1958, which were predominately of Romney blood.

The samples varied in count from 46s to 56s but were largely 46s to 50s. From each sample two adjacent staples were selected. One staple was tested for maximum load with the butt 0.75 in. held in one clamp and a test length of 2.5 in., while the other was measured for staple length and then broken by hand and placed in one of 5 grades according to its soundness. In the tender staples the distance was measured from the break to the staple butt.

The 5 grades of soundness were as follows:—

Grade 5—Sound. Unbreakable.

Grade 4—Very slight break. In this group the staples "gave" on stretching but did not break completely. A number of broken fibres could be pulled from the butt of the staple after stretching.

Grade 3—Slight break. Staples broke under strong tension.

Grade 2—Break. Staples broke under medium tension.

Grade 1—Bad break. Staples broke under light tension.

Results and Discussion

As shown in Fig. 3 a nearly perfect linear relationship was found between grade and mean maximum load. As shown in Table 7, however, the variation in maximum load between staples that were classified by hand into one grade was high, the group standard deviations being greater than the differences between the mean maximum loads of adjacent grades.

Fig. 3.—Relation between hand breaking grade and maximum load (lb/g). Test length 2.5 in.

While an effort was made to hand-break staples of similar size, this was not always possible owing to differences in the amount of wool available and to differenes in staple size associated with count number. As a result of this, some small staples would have been down-graded

TABLE 7. RELATION BETWEEN HAND-BREAKING GRADE AND MAXIMUM LOAD
(Test Length 2.5 in.)

Grade	No. of Staples	Maximum Load lb/g	Standard Deviation lb/g	Coefficient of Variation %
1	84	44.5	17.6	39.6
2	150	62.6	20.8	33.2
3	176	77.1	23.2	30.1
4	136	93.4	28.7	30.7
5	175	109.4	28.3	25.8
Total or Mean	721	81.2	32.5	40.1

in hand assessment resulting in a high mean value for maximum load for Grade 1 wools. As shown in Table 7 the group variation as expressed by the coefficients of variation % were highest for the two weakest grades. This variation illustrates a danger with hand assessment estimates particularly if these are made on a small number of staples. The correlation between maximum load and breaking grade of $r = 0.654$, while significant at the 1% level, is not as high as might be expected from Fig. 3.

Maximum load varied from 11 to 195 lb/g, showing the wide variation in staple strength found within a flock. As these sheep were running as one mob over the winter period it is apparent that some ewes were very much more liable to form a break than others. While no records are available as to whether the individual samples were from dry or pregnant ewes, the distribution of grades or maximum load results give no indication that 5% of these ewes were barren.

TABLE 8. Hand-breaking Grade and Staple Strength
(Test Length 2.5 in.)

Group	No. of Staples	Mean Staple Strength lb/g	Mean Hand-breaking Grade
1	108	203	5.0
2	112	138	5.0
3	84	134	4.5
4	136	120	4.4
5	160	95	2.9
6	142	84	2.3
7	144	67	2.2
8	160	66	2.0
9	104	50	1.6
10	100	45	1.4

Table 8 shows the mean staple strength and the mean hand-breaking grade of 10 groups of Romney wool samples broken with a test length of 2.5 in. Equal numbers of staples were machine tested and hand graded from each group. It is apparent that hand-breaking grades have not differentiated between groups 1 and 2 between which there was a large difference in staple strength. The relation between hand-breaking grade and staple strength for these results was somewhat different from that shown in Table 7, even though both series of tests were carried out by the same assessor. Groups 3 and 4 graded as 4.5 and 4.4 were stronger than grade 5 in Table 7 while group 5 graded as 2.9 was similar to the mean value for grade 4 in Table 7. It is possible that with sounder wools the level for the different hand-breaking grades are subconsciously raised and vice versa when most of the wools in a lot are tender. Study of breaking grades of the staples in Table 8 showed that there was a predominance of grades 5, 2, and 1 staples, with comparatively few staples of grades 3 and 4. There is no reason why there should be an exact linear relationship between staple strength and the arbitrarily assessed hand-breaking grades, either for different groups of

wool or for wools of similar origin. Nevertheless, probably made grade 3 samples were graded as 2 which has altered the relationship of grade to staple strength.

Another important aspect of these results is that in commercial practice only grades 1, some wools of grade 2, and an occasional grade 3 sample would be classed as tender by the wool trade. There are therefore large differences in staple strength in samples which are above the commercial classers threshold of recognition of sound wools. The significance of these differences can only be estimated, but it would be reasonable to expect from work on pre- and post-lamb-shorn wool (Story 1959) that a lower combing tear and weaker yarn would be obtained from sound wool of low staple strength than from sound wool with high staple strength.

The region at which the break or weakest point occurred in different staples from a flock would be expected to be a relatively constant proportion of staple length from the butt. The staples of grades 1 to 3 (Table 7) varied from 4.0 to 8.0 in. in length with a mean value of 5.9 in. For the 410 staples the regression was calculated between staple length and the distance from the break to the butt. From this regression it was found that the short fine 4.0 in. staple would break 44% of the distance up the staple while the long coarse 8.0 in. staple would break at 43.2%. Sheep therefore which differed widely in the length and fineness of wool which they grew were all affected at the same time by the factors causing the break. Owing to stretching and fibre straightening during hand breaking, the distance measured from the butt to the break would be a little longer than the distance to the break in the original staple.

Conclusions

The method for measuring staple strength given in this paper should form a satisfactory basis for an investigation into the incidence, causes, and effects of break and tenderness in New Zealand wool. Because of the nature of greasy wool staples, there are very many variables which will affect the measurement of staple strength. Some of these have been discussed in this paper while it is proposed to discuss others in Part II of this series. The general method of staple strength testing can be adapted according to the information required. Where maximum load only is wanted, this may be obtained without the necessity of recording breaking graphs, and a mean value may be rapidly found for a group of samples by bulking the greasy wool cut from the jaws and scouring it as a unit.

From a study of breaking graphs, a new line of approach may be made to a wide variety of research problems, such as the effect of a stress on the relation between fibres of primary and secondary follicle origin.

Above the level at which break can be determined by hand, there is a very wide range of staple strengths. This variation in the soundness of "sound" wool will no doubt have an appreciable effect on the mill processing performance of this wool.

This method would not be applicable to cotted fleeces owing to the difficulty of separating staples for testing because of fibre entanglement. No doubt an objective measure of the degree of cotting could be obtained by the force required to drag groups of staples apart using either clamps or standardised combs.

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THE PEAT SOILS OF THE AUCKLAND ISLANDS

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Summary

This paper contains a description of the peat soils on part of the Auckland Islands which lie in the South Pacific Ocean approximately 200 miles south of New Zealand. Peat forms a blanket over the surface of the Islands and is the parent material of most of the soils. In the area examined in detail the average thickness of the peat blanket was approximately 6 feet. A fossil soil horizon in the peat was dated by the radiocarbon method as 6290 ± 110 years before present. This is tentatively correlated with the post-glacial thermal maximum period any by applying the chronology established elsewhere for this period it is concluded that the blanket peats of the Auckland Islands began accumulating at least 4000 years ago. A thickness of from 2 to 6 feet of blanket peat has been built up in this time. The peat blanket is discussed with regard to origin and development, decomposition, movement and erosion, the underlying mineral material, animal contributors and chemistry.

Introduction

The Auckland Islands consist of one large and five smaller islands and lie between 50° 26′ and 50° 56′ S. latitude and 165° 52′ and 166° 22′ E. longitude. The main island covers 179 sq. miles. Adams Island, the second largest, 31½ sq. miles in area, lies to the south and is separated from the main island by Carnley Harbour. The total area of land covered by the group is 220 sq. miles (Fig. 1).

The islands are composed largely of basic volcanic rocks which were erupted from two main vents, one near Disappointment Island and the other at Carnley Harbour (Falla 1948). Marine erosion on the wind-swept west coast is rapid and in some places the western coastline has been cut back almost to the east-west divide. The east coast of the main island, with its drowned indented shoreline providing a series of fine harbours, stands in striking contrast to the high steep cliffs on the west.

The climate is not rigorous, but high humidity, persistent low cloud obscuring the sun, and frequent high winds give it a subantarctic character (Falla 1948). Most of the surface of the islands, even steep slopes, is covered with a blanket of deep peat. This peat blanket was studied by a pedologist who was included in an expedition which travelled to the Auckland Islands on HMNZS *Tui* in November 1954. A map of the islands showing the route taken by the *Tui* is shown in Fig. 1. The expedition spent only 8 days on the Islands. Detailed pedological observations were confined to the immediate vicinity of Ranui Cove, and, more particularly, the area between the camp and the Lookout, a wartime coast-watching station situated on a plateau 180 ft above sea level and about half a mile north-west of the camp (Figs. 1, 2).

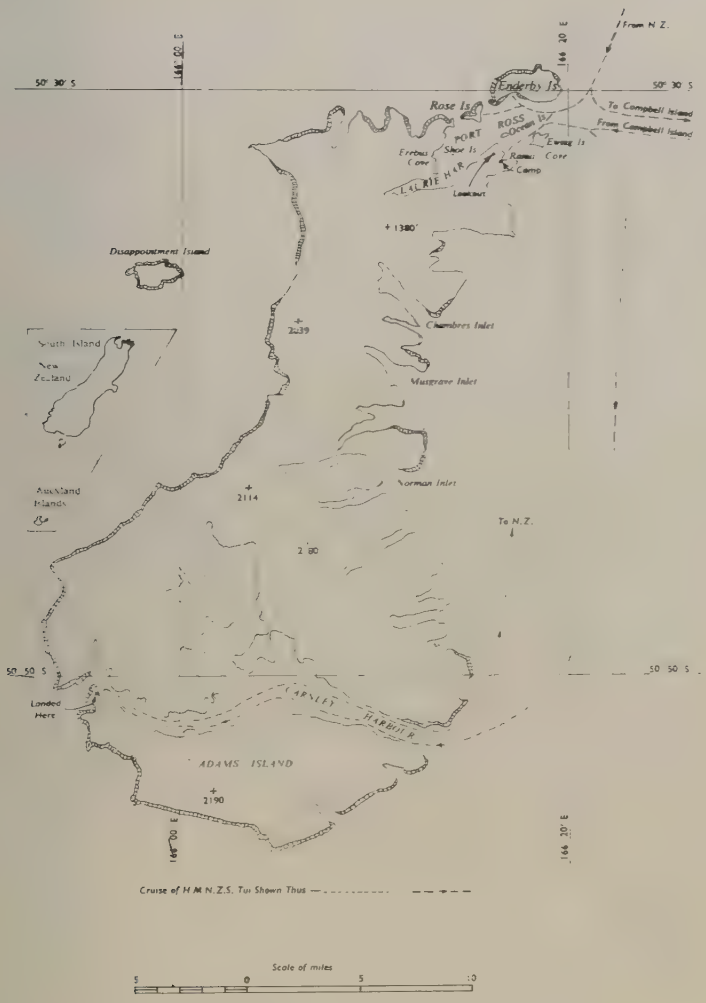

Fig. 1.—Map of the Auckland Islands.

DESCRIPTION

Climate

Some climatic data are available for the Auckland Islands. Observations were made from 1941 to 1944, mainly at Carnley Harbour in the south, and the results are set out in Table 1. Temperatures (°F) range from an extreme maximum of 68° to an extreme minimum of 27° with a mean temperature of 46°. The mean annual rainfall at Port Ross is 59.8 in. and at Carnley Harbour 82.6 in. over 331 rain days. An estimated mean over the group is 70–75 in.

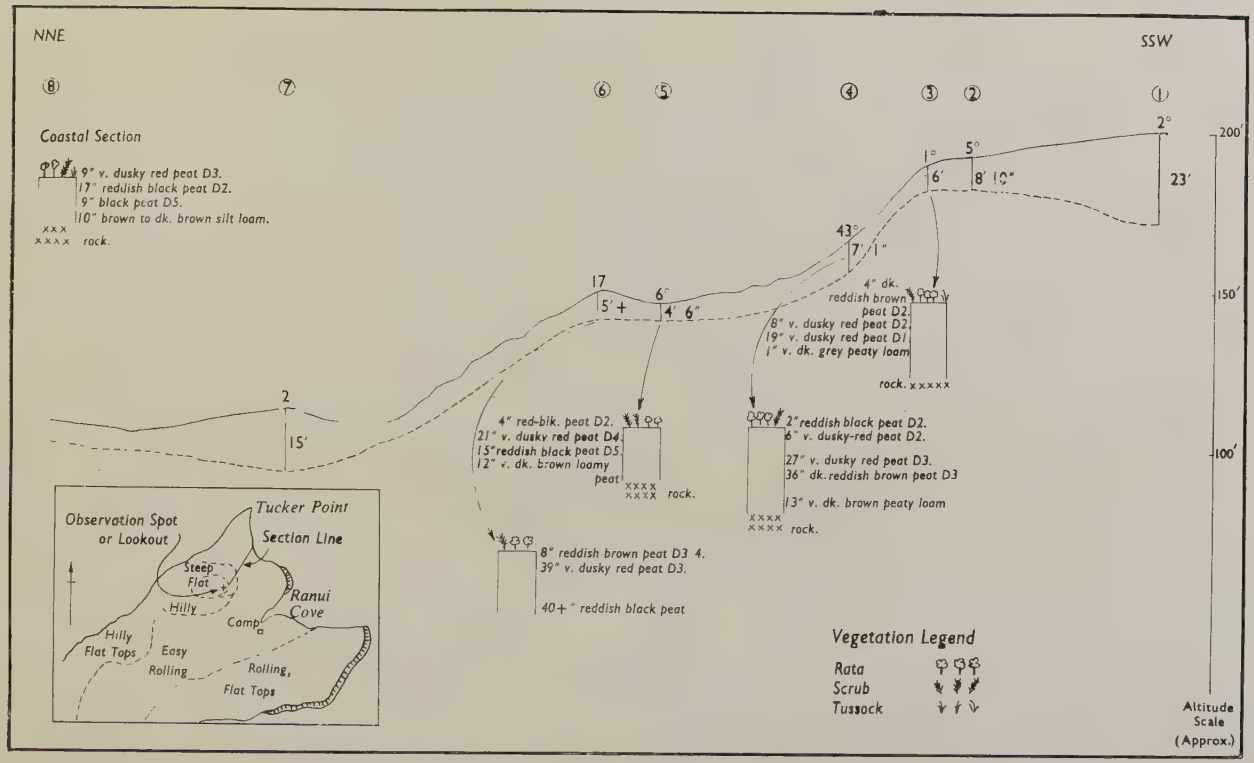

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Fig. 2.—Diagrammatic Section showing the relationship between the peat blanket and topography. Horizontal scale approximately 20 yd = 1 in. Inset shows location of transect and topography in the vicinity of Ranui Cove.

TABLE 1. METEOROLOGICAL DATA, AUCKLAND ISLANDS (CARNLEY HARBOUR)
(May 1941–May 1944)

Month	Pressure* (mb)			Temperature (°F.)					Mean* Relative Humidity (%)	Mean Cloud Amount (tenths)	Mean Rainfall			Average No. of Days of					
	Mean	Highest	Lowest	Mean†	Mean Daily Max.	Mean Daily Min.	Extreme Max.	Extreme Min.			Inches	Raindays	Max. Daily Fall	Gale	Snow	Hail	Thunder	Fog	Grass min. below 32°F.
Jan.	1005	1027	971	50	55	45	65	35	83	8.9	7.21	25	1.61	6	—	—	—	—	—
Feb.	1006	1027	984	51	56	45	66	38	87	8.6	5.66	24	1.68	2	—	2	—	2	—
Mar.	1008	1025	980	50	55	45	68	37	87	9.2	5.73	26	1.09	5	—	5	—	2	—
Apr.	1004	1030	979	47	51	42	60	29	89	9.5	9.79	28	4.04	7	1	5	—	3	—
May	1006	1032	982	43	47	38	52	27	89	9.1	9.25	29	1.94	7	5	10	1	—	3
Jun.	1008	1031	972	42	46	38	56	30	93	8.8	7.36	29	2.46	4	3	6	—	2	2
Jul.	1010	1033	985	43	48	38	58	29	91	8.5	5.33	29	1.16	4	2	7	—	—	2
Aug.	1009	1025	987	42	47	37	55	28	88	8.8	7.33	30	1.13	6	5	7	1	2	2
Sep.	1005	1023	977	44	49	39	59	30	87	8.9	5.88	29	0.81	8	3	7	—	1	1
Oct.	1008	1033	985	44	50	39	61	31	83	8.7	5.06	29	0.95	7	4	8	—	2	—
Nov.	1003	1024	967	45	51	40	60	30	81	8.7	5.43	25	1.36	8	2	9	—	1	—
Dec.	1003	1023	983	47	53	41	62	27	85	9.0	8.58	28	1.23	9	1	8	—	—	—
Means	1006	—	—	46	51	41	—	—	87	8.9	—	—	—	—	—	—	—	—	—
Totals	—	—	—	—	—	—	—	—	—	—	82.61	331	—	73	26	74	2	15	10
Extremes	—	1033	967	—	—	—	68	27	—	—	—	—	4.04	—	—	—	—	—	—

* Observations at 0900 h./N.Z.S.T. (2130 G.M.T.)
† ½ mean daily (max. + min.)

NOTE.—Annual rainfall at Port Ross over the period May 1941–May 1945 was 59.8 inches. An estimated mean annual rainfall over the group is 70–75 inches.
Temperature records were incomplete during 1943.

Physiography

Most of the 220 square miles of land surface of the Auckland Islands is covered with peat. During the eight days spent on the islands the only peat-free areas observed were rock outcrops and approximately 20 acres of sandhills behind Sandy Bay on Enderby Island. The rock outcrops, which appeared to be lava flows, give rise to small screes. Apart from these screes no obvious erosion scars were observed on any of the islands, although the hummocky surface of the peat on hilly and steep slopes might indicate a downhill movement. In the vicinity of Port Ross, between Ranui Cove and Tucker Point, the peat-covered surface terminates abruptly in cliffs up to 15 ft high, but there seems to be a tendency for the peat to flow over the edge of the low cliffs and to produce an even slope down to the water's edge.

The main island is drained by small streams, most of which flow in broad V-shaped gullies. The water in the streams flowing into Ranui Cove is stained dark brown by dissolved organic matter and appears to carry little material in suspension.

Vegetation

The plant associations growing on the peat may be divided into three broad groups.

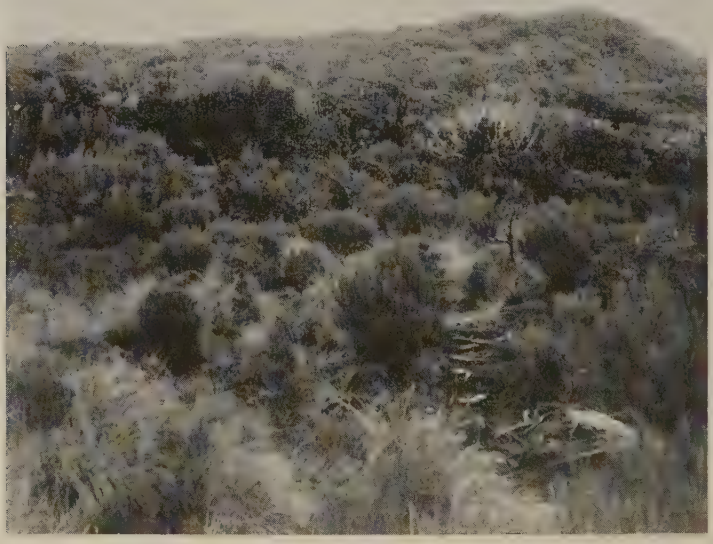

Fig. 3.—A section of the track to the Lookout, Ranui Cove. Tussock (*D. antarctica*) in the foreground, scrub (mainly *Dracophyllum* and *Suttonia*) in the middle background and rata forest in the far background.

1. Southern rata (*Metrosideros umbellata*) forest occurs in a belt around the coast, extending about a quarter of a mile inland. On exposed sites trees are stunted and deformed but in sheltered places individual trees attain a height of up to 30 ft. (Fig. 3). Under rata forest the ground is covered with a close mat of moss, liverworts and lichens, which makes a very slippery surface (Fig. 5). Isolated patches up to 2 in. thick of dead rata leaves lie on the surface. Associated trees and shrubs include several species of *Coprosma*, the haumakoroa (*Nothopanax simplex*), the inaka (*Dracophyllum longifolium*), and *Suttonia divaricata* (Cockayne 1927).

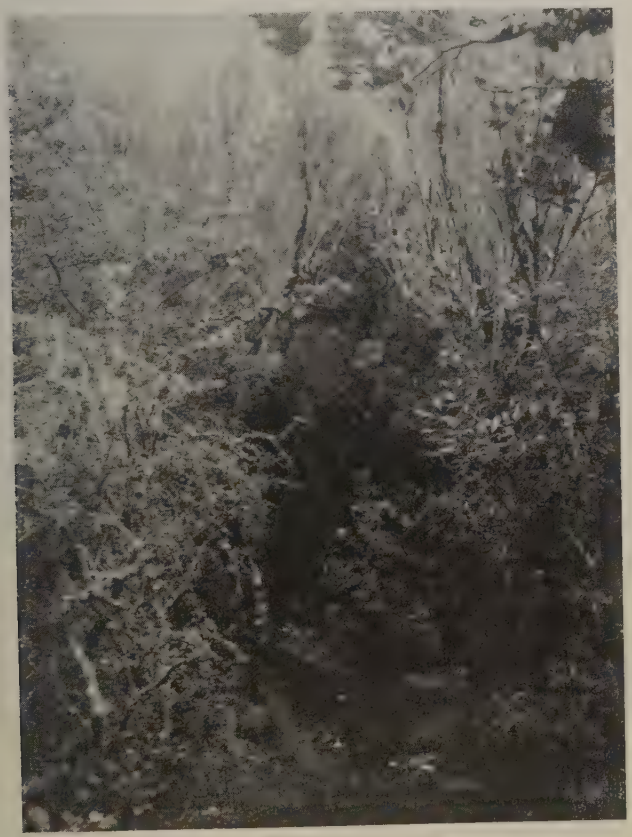

Fig. 4.—Dense vegetation consisting of mainly *Suttonia, Dracophyllum,* and rata in the vicinity of Ranui Cove.

2. Above the forest line there is a dense vegetation of rata and scrub in which *Suttonia divaricata* is dominant. It is associated with stunted rata, inaka, and several species of coprosma (Fig. 4).

Fig. 5.—Section through the top horizons of profile 4. Note the moss-liverwort-lichen mat on the surface.

3. A mixed association of tussock grassland, consisting mainly of the large tussock (*Danthonia antarctica*) and various herbaceous plants, is dominant at higher altitudes. Its lower limit varies from about 300 ft above sea level in the north to about 100 ft above sea level in the south (Fig. 6). In the north, patches of *D. antarctica* and the subantarctic poa (*Poa litorosa*) occur interspersed among the rata forest and scrub associations at altitudes lower than 300 ft.

In detail this vegetation pattern is a mosaic. Thus although the plateau upon which the Lookout is situated lies within the rata-scrub zone, it supports an association consisting mainly of *Oreobolus pectinatus* and *Gaimardia ciliata*, with some stunted rata and tussock (*D. antarctica*) (Moar 1958 p.452).

The Peat

In order to study the relationship between the peat blanket and topography, a transect was selected (Fig. 2) which traversed a variety

of slopes from the Lookout plateau to the lowland approximately 100 ft below. Eight sites were examined, and the observations are summarised in Fig. 2. The section along this transect line shows that a layer of peat with an average thickness of approximately 6 ft overlies rock on all slopes. Depths recorded by Moar show appreciable thickening of the peat to about 23 ft on the flat plateau top (site 1) and to about 15 ft in a depression on the lowland below (site 7).

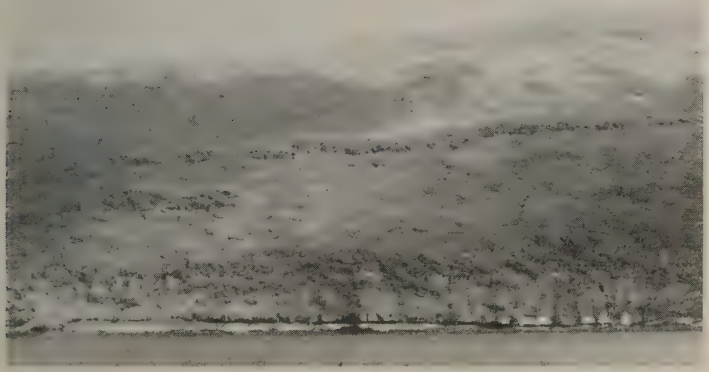

Fig. 6.—Adams Island from Carnley Harbour. The rata and scrub at low levels give way to tussock with increasing altitude.

Full profile descriptions at sites 3, 4, 5, 6, and 8 are given in Appendix 1. These sites were also sampled for chemical analyses and the results are given in Table 2.

In all profiles studied in detail some mineral material lay between the peat and the underlying rock (see also Moar 1958 pp. 458-9). At site 3 there was ½ to 1 in. of very dark grey peaty loam at 71 in. At site 4 the peat was slightly loamy at 66 in.; at 72 in. there were dark brown to brown patches of peaty loam which merged with increasing depth into dark brown to very dark brown peaty loam. At site 5 a 12-in. layer of very dark brown loamy peat was identified at 40 in. At site 8, 10 in. of brown to dark brown silt loam was found under 36 in. of peat. This mineral horizon is distinct both in colour and texture from the overlying peat and lies immediately beneath a horizon of strongly decomposed black peat which differs markedly in colour and degree of decomposition from the peat higher in the profile (Fig. 7).

A striking feature of all the profiles examined was their unexpected dryness. Four pits were dug on slopes of 1°, 43°, 6°, and 17° and were left open for periods of up to 24 hours. Ground water did not run

Fig. 7.—Peat and underlying mineral soil exposed in a small cliff. The declivity of the cliff has been reduced by peat sliding over the edge—the white line marks the top of the cliff. The stones imbedded in the peat to the right of the spade are thought to have been deposited there by waves during storms.

into any of them. Two feet of water collected in the bottom of one pit that was left open overnight, but heavy rain fell during the night and the pit was in a position to collect surface run-off. Furthermore, water disappears quite rapidly from the surface after rain. Eight hours after a period of heavy rain which lasted for 24 hours, the surface under rata and scrub was in the same condition as it had been before the rain i.e. moist and slippery but not wet—no pools of water lay on the ground.

In every profile described in detail the degree of decomposition of the peat in the major horizons was estimated according to a field scale (D1-D10) following that used by von Post (1937) and based on an estimation of the amount of organic colloids present. Nowhere was there found a state of decomposition greater than D6, i.e. strongly decomposed.

Profiles 5 and 8 were the only two in which rock was exposed beneath the peat and in both cases the lowest organic horizon of reddish-black to black peat was determined as D6.

DISCUSSION

Origin and Development

The dominance of peat formation throughout the Auckland Islands under various plant communities and on a wide range of slopes suggests a climatic cause.

Rainfall is high and temperatures are low, the estimated mean annual rainfall over the group being 70–75 in. and the mean annual temperature 46°F. The high mean relative humidity (87%) and the high mean cloud cover (8.9), allied to the low atmospheric temperatures, must result in a low rate of evaporation from the soil. On Chatham Island Wright (1959) suggested that salts blown inland from the sea had assisted peat development through retardation of plant decomposition. This suggestion may equally well apply to the Auckland Islands where large amounts of cyclic salt would be expected in the rainfall.

Aston (1909) concluded from his observations on their moisture status that the soils of the Auckland Islands, considering that they receive a daily or almost hourly rainfall, are naturally well drained. The following observations support this conclusion:

(a) the relative dryness of the top horizons.

(b) the distinct change in the depth of the peat and in the nature of its vegetative cover on sites that are naturally poorly drained. Two such localities were observed (Fig. 2, sites 1 and 7). In both these places features such as depressed margins and raised centres suggest raised bogs or convex basin peats (Moar 1958, p. 459). At both these sites the vegetation consists of an association of tussock grassland and herbaceous plants.

(c) the relatively rapid disappearance of surface water from the ground after rain (p.533).

Apart from the higher parts of some raised bogs, intrazonal peat deposits are invariably slow draining.

Climate would thus appear to be the dominant factor in peat formation in the Auckland Islands, blanket peat being the zonal soil of the region. Variations are due mainly to the intrazonal influence of topography which may produce a local accumulation of ground water and a consequent thickening of the peat blanket.

Decomposition

Field observation on the peat soils of the Auckland Islands suggest that they are not, in general, strongly decomposed. The moderately low D numbers, which are a measure of the organic colloidal material present, and the fact that in most horizons there are recognisable plant remains, provide the main field evidence for this conclusion. Chemical evidence is not so conclusive. All the horizons analysed have

very high values for cation-exchange capacities (112 to 233 me.%), probably indicating strong decomposition. However, this is by no means certainly established on the basis of these figures alone, for there does seem to be a correlation between strong acidity and high cation-exchange capacity. In intrazonal peats of the North Island of New Zealand, strongly acid peats generally have higher cation-exchange capacity and lower base-saturation figures than less acid peats. The Auckland Island peats are extremely acid (pH range 3.7 to 4.6) and have low base-saturation figures (44% to 19%).

All the profiles examined in detail were developing under apparently predominantly aerobic conditions with humification probably the dominant process of decomposition. The high C/N ratios (46–68) for all samples, except 6638 A–D which are discussed later, suggest that if humification is an active process it is not very effective, possibly because the parent material of these peat soils is supplied by predominantly woody plants and probably contains a high proportion of substances which are relatively resistant to decomposition. Furthermore, it is possible that in profiles occupying well-drained positions (e.g. profiles 3, 4, and 6) eluviation and subsequent downslope flushing have removed a considerable amount of the colloidal products of humification, leaving resistant residues which have relatively high C/N ratios and relatively low D numbers.

It seems probable that anaerobic conditions exist in the lower horizons of profiles 1 and 7 which are situated on small raised bogs. The vegetation, structure, and position in the landscape of these raised bogs suggest an abnormal accumulation of ground water. The slowing down of decomposition because of anaerobic conditions has led to a relative increase in accumulation and a consequent thickening of the peat blanket in these localities.

Marked profile differentiation was seen in two profiles (Nos. 5 and 8). In profile 5 a reddish black horizon of strongly decomposed, friable, greasy peat with a high C/N ratio (59) and a very high cation-exchange capacity (233 me.%) occurs at approximately 2 ft below the surface. The upper horizons are very weakly to moderately decomposed and have slightly lower cation-exchange capacities (112, 191 me.%) although there is little difference in C/N ratios (58, 46). In profile 8 the lowest peat horizon about 2 ft below the surface consists of black, soapy, strongly decomposed peat with a relatively low C/N ratio. The upper horizons of this profile also have low C/N ratios, the reasons for which are discussed later. This lowest peat horizon in profile 8 has been dated by radiocarbon method at 6290 ± 110 years before present (Messrs Fergusson and Rafter, pers. comm.). This indicates that the marked profile differentiation in these two profiles is caused by the presence of a fossil soil buried by 2 to 3 ft of more recent peat. The peat in the fossil soil horizons is strongly decomposed because it is older than the overlying peat and because, in all probability, it was formed under a warmer climate. Profiles 3, 4 and 6 show little profile differentiation apart from colour changes.

Movement and Erosion

Aston (1909) observed evidence of bog slides on the Auckland Islands and noted several fresh scars, particularly around Carnley

Harbour, which he attributed to this form of erosion. No recognisable scars were seen during the 1954 expedition, but the following evidence indicates that the peat does move down slope:

(a) the steep slope on which the section was located at the Observation Spot, Port Ross, is broken by several undulations. The largest of these takes the form of a depression with a distinct mound at the outside edge (see profiles 5 and 6, Figure 2). There is an appreciable thinning of the peat in the depression behind the mound, and a thickening on the mound itself. This feature may have been caused by a small peat slide checked perhaps by a dense growth of forest. There appeared to be no thinning of the peat on the steep slope behind the depression and in fact shallow profiles were recorded only immediately behind the mound. If the peat is constantly moving down-slope the scar caused by this peat slide on the steep slope immediately behind the depression could have been healed from the slopes above and only on the gentle slope of the depression behind the mound are the effects of the slide still noticeable.

(b) In many places along the stretch of coast between Ranui Cove and Tucker Point the peat almost completely covers the face of a low cliff (Fig. 7).

It is apparent from (a) that in addition to slow flow the peat blanket is subject to rapid slides. These appear to take place on steep slopes where the slow down-slope movement of the peat is impeded by vegetation. The peat builds up behind the obstruction until the increasing weight overcomes the barrier and a small land-slide occurs. Thus slow movement of peat down-slope, accelerated occasionally by a rapid slide, is the major process of erosion operating on these soils.

It would seem that two processes are affecting the surface level of the peat. Creep and slides are lowering the surface; and dense vegetation and slow decomposition are adding to the peat deposits. The latter process is more effective than the former with the result that the peat deposits and the land surface in general are building up at the present time.

Nowhere in the Auckland Islands was any evidence seen that would indicate the degeneration of the peat by the natural development of cracks or channels, and consequent erosion, as has been observed on some Northern Hemisphere blanket peats (Fraser 1933).

Underlying Mineral Material

In all the profiles described in which rock was reached, a horizon with high mineral content was encountered immediately above the rock. As described in Appendix 1, the mineral horizon ranges from a few inches of black loamy peat to 10 in. of brown to dark brown silt loam. This material may possibly be derived from the weathering of rock outcrops in the uplands and carried down in the peat. However, the fine texture of the material and the well defined nature of the horizon does not support this view. In the high-moor peats of

Macquarie Island, which are from 3 to 5 ft thick, mineral matter occurs both evenly distributed throughout the peat and also as a distinct, sharply defined horizon. The evenly distributed material is considered to be derived from landslips (Law and Burstall 1956).

Alternatively, it is possible that this mineral material is being weathered at present from the basalt underlying the peat, but the dating of the peat horizon immediately above the 10 in. of silt loam in profile 8 at 6290 ± 110 years suggests that these two horizons represent a fossil soil, and that the silt loam was weathered from the basalt before the accumulation of the present blanket peat. Such a soil would develop under warmer conditions than at present prevail in the Auckland Islands. The date of 6290 ± 110 years suggests a correlation with the post-glacial thermal maximum period which has been dated by Horberg (1954, quoted by Stevens 1956, p.227) as 7000 to 4000 years ago. The date obtained from the Auckland Islands may not mark the close of the thermal maximum because the sample site was an estimated 5 ft above sea level and Stevens (1956, p.227) concluded that the highest sea level attained during the thermal maximum in the Hutt Valley district was 10 ft above present-day mean sea level, which he tentatively dated as about 4000 years ago. It seems strange that the Auckland Island fossil soil has remained so well preserved if indeed it has been inundated by a rise of sea level, but in view of the dates obtained in other parts of the world for the close of the thermal maximum period, this possibility cannot be excluded. By applying the date established overseas for the close of the thermal maximum it would appear that the blanket peats of the Auckland Islands are at least 4000 years old.

On the evidence of profiles 5 and 8, where the fossil soil was definitely identified, between 2 and 3 ft of blanket peat have accumulated in this time, but in profiles 3 and 4, where peaty loam textures are the only indication of a fossil soil, the evidence suggests that a blanket of peat 5 to 6 ft thick has been formed in the present cycle.

Animal Contributors

The Auckland Islands abound in sea lions and oceanic birds such as penguins, shags, and petrels (Falla 1948, p.142). Many of these creatures make periodic contact with the soil either by burrowing into it, settling temporarily on it or travelling across it, and some of the chemical features of profile 8 and the profile sampled on Campbell Island provide an interesting example of the effect animal life can have on soil formation.

The total nitrogen values of samples from these two profiles are very high and they display lower carbon-to-nitrogen ratios than do the others. In New Zealand, ratios of 50–60 are usual for acid peats (see Soil Set 110, p.214, N.Z. Soil Bureau Bull. n.s. 5) and compared with these the ratios for samples 6638 A-D and 6644 A-C are low for acid peats and may not express exactly the degree of decomposition. They may be partly influenced by an influx of nitrogen from animals and this view is supported by the following observations:

(a) The samples having lower C/N ratios were taken from near the sea where modification by birds and seals could well occur,

(b) Several soil samples analysed previously, and known to have been altered by animal life, have shown similarly low C/N ratios. Examples are shown in Table 3 and it may be seen from these results that:

Sample No. 2976A from Bream Island had a pH of 3.5, a C/N ratio of 13 and contained free nitrate.
Sample No. S.B. 6668, a sample collected by Dr Falla from the bottom of a petrel's burrow on Ocean Island, Auckland Islands had a pH of 3.3 and while the organic carbon content was very high, the C/N ratio was kept low (13) by a very high nitrogen content.
Sample Nos. S.B. 6663 A, B, C, D, collected by Mr W. T. Ward from Stephens Island, had a top-soil C/N ratio of 11, dropping to 5 further down the profile.

(c) High citric-soluble-phosphorus figures were obtained from the soils in Table 3 and may be regarded as resulting from animal excreta. The lower horizons of the soils from site 8 and from Campbell Island are also higher in phosphorus than are other samples in Table 2. The mineral horizons of these two profiles contain extremely high contents of citric-soluble phosphorus and it may be that most of the phosphorus from the animals has passed through the peat to be held by the underlying mineral material. On the other hand, the extremely high figures may be due to the naturally high phosphorus content of the basaltic parent material of these mineral horizons.

(d) Potassium figures are higher in the lower horizons of profile 8 than in those of profile 5 which is to be expected if animal excreta have been added to the former. The exchangeable potassium figures in the samples quoted in Table 3 are also high, especially in relation to the other bases present.

Chemistry

Analyses of profiles 8, 5, 6, 3, 4, a sample of calcareous sand from Enderby Island, and also of a soil sampled at Campbell Island are shown in Table 2.

With the exception of samples 6638D, 6641, 6644B and 6644C (which are mineral soils) the samples analysed are peats which have similar losses on ignition and which are all extremely acid.

The cation-exchange capacities of the organic layers are all very high and vary considerably. The cation-exchange capacities of the mineral horizons 6638D and 6644C are also very high and this is probably due to the decomposed basalt parent material which can have high ion-exchange properties without being strongly weathered, as has been found by Dr L. D. Swindale (pers. comm.) for soils derived from basalt in Central Otago, N.Z.

Samples 6638 and 6639 were analysed both for exchangeable bases and for bases in the ash. They were chosen for more detailed analyses because they afforded interesting comparisons between a coastal profile (Profile 8—6638) and a profile from a higher altitude and further from the sea (Profile 5—6639). As well as the probable differences due to

TABLE 2(a). Chemical Analyses

Auckland Islands Samples collected by M. L. Leamy
Campbell Islands Samples collected by N. M. Ridgway

Analysed by E. A. Christie and J. C. Jennings.

Location	Profile No.	Sample No.	Depth (in.)	Carbon %	Nitrogen %	C/N	Analyses of Ash							
							Loss on Ignition %	Alkalinity Ash me.%	% Acid Insol. Res.	Total Ca me.%	Total Mg me.%	Total K me.%	Total Na me.%	$CaCO_3$%
Tucker Point Port Ross	8	6638A	1– 9	55 *	2.10	26	95.7	53	0.52	19.2	35.1	4.2	31.4	
		6638B	10–20	55 *	1.79	31	95.9	55	0.13	15.4	29.2	3.4	38.2	
		6638C	28–34	50 *	1.38	36	87.4	28	7.80	19.7	18.4	1.9	19.5	
		6638D	36–40	3.0	0.15	20	10.4	12	85.0	4.7	9.8	1.3	5.5	
Below Obs. Spot, Ranui Cove, Port Ross	5	6639A	1– 4	56 *	0.97	58	97.5	38	0.19	20.9	20.8	3.6	7.9	
		6639B	5–25	55 *	1.20	46	97.1	52	0.14	27.0	32.4	1.1	8.0	
		6639C	26–40	55 *	0.93	59	96.3	66	0.28	35.0	41.0	0.9	7.3	
		6639D	41–52	52 *	0.85	61	90.7	29	4.54	19.0	17.0	0.8	4.3	
As for 6639	6	6640A	0– 8	56 *	0.89	63	98.4	30						
		6640B	8–47	56 *	0.89	63	98.3	30						
Obs. Spot, Ranui Cove, Port Ross	3	6642A	6–12	56 *	1.17	48	98.3	43						
		6642B	13–18	56 *	0.83	68	97.9	46						
	4	6643A	3– 7	56 *	0.98	57	97.8	35						
As for 6639		6643B	8–35	56 *	0.87	64	97.6	41						
		6643C	36–48	55 *	0.84	65	96.7	53						
Perseverance Har. Campbell Island		6644A	12–48	56 *	1.65	34	97.6	26						
		6644B	48–108	30.6	1.13	27	67.2	18						
		6644C	108–114	1.1	0.08	14	5.3	13						
Behind Sandy Beach, Enderby Island		6641	2–12	1.5	0.25	6								17.2

* As our soil analysis methods are not suitable above 40% carbon these figures have been determined by:— $\frac{\text{Loss on ignition}}{1.75}$

TABLE 2(b). CHEMICAL ANALYSES

Auckland Islands Samples collected by M. L. Leamy
Campbell Islands Samples collected by N. M. Ridgway

Analysed by E. A. Christie and J. C. Jennings.

Location	Profile No.	Sample No.	Depth (in.)	pH	Decomp.* Nos.	Cation Exchange Results							1% Citric Soluble P_2O_5		
						C.E.C. me.%	TEB me.%	% Base Saturation	Ca me.%	Mg me.%	K me.%	Na me.%	Inorganic %	Total %	% Inorganic of total
Tucker Point	8	6638A	1– 9	4.6	D4	144	63	44	13.7	20.2	4.3	29.2	0.028	0.029	97
		6638B	10–20	4.1	D3	174	60	35	10.5	20.0	3.2	38.0	0.018	0.020	90
		6638C	28–34	3.8	D6	144	53	37	6.8	15.6	1.5	19.0	0.019	0.022	86
		6638D	36–44	4.4		53	17	32	3.1	8.9	1.4	6.8	0.241	0.370	65
Below Obs.	5	6639A	1– 4	4.3	D3	112	42	38	18.1	13.9	3.6	6.1	0.047	0.052	91
		6639B	5–25	4.1	D5	191	56	29	20.8	19.5	0.8	6.3	0.006	0.008	75
		6639C	26–40	4.2	D6	233	72	31	28.6	29.4	0.9	6.7	0.004	0.004	100
		6639D	41–52	4.0		150	30	20	12.3	14.0	0.5	4.0	0.007	0.007	100
As for 6639A	6	6640A	0– 8	3.9	D4–5	134	33	25					0.022	0.025	88
		6640B	8–47	3.7	D4	175	33	19					0.008	0.010	80
Behind Sandy Beach, Enderby Island		6641	2–12	7.7											
Obs. Spot, Ranui Cove, Port Ross	3	6642A	6–12	4.0	D3	121	28	23					0.010	0.012	83
		6642B	13–18	3.9	D2	190	46	24					0.009	0.010	90
		6643A	3– 7	3.9	D3	146	40	27					0.023	0.027	85
As for 6639A	4	6643B	8–35	3.9	D4	203	59	29					0.015	0.016	94
		6643C	36–48	4.0	D4	213	63	30					0.003	0.004	75
Perserverance Har. Campbell Island		6644A	12–48	3.6		144	21	15					0.007	0.007	100
		6644B	48–108	3.7		95	13	12					0.186	0.206	90
		6644C	108–144	5.1		59	18	30					0.311	0.313	99

* As determined by M. L. Leamy in the field.

TABLE 3. SOIL SAMPLES ANALYSED PREVIOUSLY WHICH HAVE BEEN ALTERED BY ANIMAL LIFE

Location	Lab. No.	Depth in.	pH	1% Citric Sol. P_2O_5 %	C %	N %	C/N.	C.E.C. me.%	B.S. %	Exch. Ca. me.%	Exch. Mg. me.%	Exch. K. me.%	Exch. Na me.%
Bream Is.	2976A	0– 6	3.5	0.955	11.8	0.92	13	56.7	11	4.2	2.2	1.5	
	B	6–12	2.7	0.813	6.7	0.38	18	56.0	3	1.4	0.7	0.9	
Ocean Is.	S.B.6668		3.3	0.070	31.4	2.50	13						
Stephens Is.	S.B.6663A	0– 6	3.8	0.462	8.3	0.76	11	38.0	14	3.0	0.8	0.70	0.7
	S.B.6663B	6–12	3.0	0.415	6.8	0.60	11	39.6	2	0.2	0.0	0.65	0.3
	S.B.6663C	12–18	3.0	0.438	5.9	0.45	13	39.1	2	0.2	0.2	0.85	0.5
	S.B.6663D	18–24	3.0	0.438	0.7	0.13	5	19.5	4	0.1	0.0	0.55	0.1

NOTE.—Profiles 2976 and S.B.6663 contained free nitrate.

animal activity, there may be differences caused by degree of exposure to cyclic salt. The results indeed show a marked difference in sodium figures—those for the coastal profile being much higher than those for the inland profile. However, the rise for magnesium, which is usually associated with cyclic salt effect, is not apparent and is possibly being masked either by return of magnesium from vegetation or by mixing of the peat with the underlying olivine basalt.

It is interesting to note that the increase in calcium and magnesium in the more strongly decomposed horizon of profile 5 (6639C) is not acompanied by an increase of potassium. The potassium content of the top horizon is high and it would seem that this due either to leaching of the older material or to a faster uptake and return of this element by the vegetation.

Conclusions

In this study, the peats of the Auckland Islands have been treated as soils rather than as accumulations of plant remains, in the belief that pedological techniques can add to the understanding of peat deposits. The main conclusions are:

(1) That blanket peat is the zonal soil of this region.

(2) That the thickness of the peat blanket is approximately constant on all angles of slope from 1° to 43°, with the exception of poorly drained flat surfaces or depressions where the development of intrazonal peats produces an appreciable thickening of the blanket.

(3) That the main processes operating in the zonal soils are accumulation, aerobic decomposition, and possibly eluviation.

(4) That accumulation of blanket peat is opposed by only weak erosive forces, which is resulting in the land surface of the Auckland Islands being slowly built up.

(5) That the present peat-forming period dates from the close of the post-glacial thermal maximum period.

(6) That the activities of animals such as birds and seals have considerably affected the chemistry of some coastal soils.

Acknowledgments

The authors wish to acknowledge the help of the following: Mr N. T. Moar, Botany Division, DSIR, who supplied some of the measurements of peat depths and also identified many plants.

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APPENDIX 1—Detailed Profile Descriptions

Profile 3

Location:	11 yards NNE of Observation Spot, Ranui Cove.
Height:	184 ft. above sea level.
Slope:	1°.
Aspect:	NNE.
Vegetation:	Rata (*Metrosideros umbellata*)—4 to 5 ft high, stunted; *Dracophyllum longifolium*—2 to 3 ft high; tussock (*Danthonia antarctica*); lichen and moss, liverwort.
Profile:	
½–1 in.	dark reddish brown (5YR 2/2) peat; D3; plant remains predominantly mosses, liverworts and lichens, many rata roots (living); the surface is covered with a mat of liverwort, moss, and lichen; when this peat is squeezed a little turbid brown water appears; clear wavy boundary;
3½ in.	dark reddish brown (5YR 2/2) peat; D3; plant remains fine matted roots and tussock leaves, many rata roots (living); clear smooth boundary;
8 in.	very dusky red (2.5YR 2/2) peat; D3; plant remains roots and twigs of woody plants (probably rata) and some tussock leaves; gradual irregular boundary;
19 in.	very dusky red (2.5YR 2/2) peat; D2; plant remains large pieces of woody plants black throughout and some tussock leaves.
	At 5 to 6 ft the peat becomes black (5YR 2/1) and so dry that no moisture was extracted by hand pressure. No recognisable plant remains. At 6 ft the basalt was reached. There appears to be about ½ to 1 in. of mineral soil above the rock—very dark grey (5YR 3/1) peaty loam.

Profile 4

Location:	About 30 yd NNE of Observation Spot, Ranui Cove.
Height:	166 ft above sea level.
Slope:	43°
Aspect:	NNE
Vegetation:	Moss, liverworts, and lichens, *Dracophyllum longifolium, Hebe elliptica, Suttonia divaricata, Uncinia* sp., rata (*M. umbellata*).
Profile:	
2 in.	reddish black (10R 2/1) peat; D3; abundant roots, plant remains moss, liverwort, dracophyllum; abrupt smooth boundary;
6 in.	very dusky red (2.5YR 2/2) peat; D3; abundant roots including large rata roots; plant remains small roots, medium

roots, and some small woody twigs, friable; diffuse wavy boundary;

27 in. very dusky red (2.5YR 2/2) peat; D4; many roots; plant remains rata roots and twigs; there are some firm, fibrous, shiny when broken, veined remains which may be rata leaves; firm; clear smooth boundary;

30–36 in. dark reddish brown (5YR 2/2) friable peat; D4; few to many roots, plant remains woody twigs and roots.

At 66 in. the peat is slightly loamy. At 72 in. spots of dark brown to brown mineral material of peaty loam texture appear. Between 72 and 80 in. this becomes a dark brown to very dark brown greasy peaty loam. Basalt at 85 in.

Profile 5

Location: About 75 yd NNE of Observation Spot, Ranui Cove.
Height: 150 ft above sea level.
Slope: 6°.
Aspect: NNE.
Vegetation: Liverworts, moss, *Suttonia divaricata, Nothopanax simplex,* rata (*M. umbellata*), *Dracophyllum longifolium.*

Profile:

4 in. reddish black (10R 2/1) peat, fibrous; D3; abundant roots; plant remains sedge-like leaves, rata leaves, small roots;

21 in. very dusky red (2.5YR 2/2) firm peat; D5; many roots; plant remains woody twigs and roots (probably rata) also sedge-like leaves; large round patches (up to 9 in. in diameter) of a dark reddish brown (2.5YR 3/4) colour throughout this horizon seem slightly less decomposed (D4); clear smooth boundary;

15 in. reddish black (10R 2/1) friable greasy peat; D6; few roots; woody branches or twigs the only recognisable plant remains; lighter patches of a very dusky red (10R 2/2) colour which are firmer than the matrix, but are more diffuse and less well defined than those of the above horizon; peat silty at the base of this horizon;

12 in. very dark brown (10YR 2/2) greasy loamy peat, massive, sticky, non plastic, contains carbonaceous material including recognisable twigs and branches; a discontinous brown (10YR 4/3) band at the top of this horizon.

on weathered basalt.

Profile 6

Location: About 90 yd NNE of Observation Spot, Ranui Cove.
Height: 154 ft above sea level.
Slope: 17°.
Aspect: NNE.
Vegetation: Rata (*M. umbellata*), *Suttonia divaricata, Dracophyllum longifolium,* moss, lichen.

Profile:

8 in. reddish brown (5YR 2/2) friable peat; D4-5; abundant roots; plant remains small woody twigs and roots;

39 in. very dusky red (2.5YR 2/2) firm fibrous peat; D4; many roots; plant remains mostly large red woody fragments (rata);

on 40 in. reddish black (10R 2/1) soft non-fibrous peat containing few roots and medium and large woody fragments.

Profile 8

Location: At the head of the first bay NNW of Ranui Cove. Profile exposed in cliff section.
Height: About 5 ft above sea level.
Slope: 12°.
Aspect: N to NE.
Vegetation: *Uncinia* sp. (a sedge), tussock (*D. antarctica*), *Hebe elliptica,* rata, *Dracophyllum longifolium,* small ferns, *Poa litorosa,* moss, and liverworts.

Profile:

2 in.	dead twigs, leaves and bark of dracophyllum tussock, hebe and rata;
½ in.	dark reddish brown (5YR 2/2) matted roots of small plants probably liverworts and moss; clear wavy boundary;
9 in.	very dusky red (2.5YR 2/2) peat; D4; many living roots; plant remains small roots, tussock stems and leaves, woody twigs (probably hebe)—sometimes lighter coloured patches are associated with the woody material; clear smooth boundary;
17 in.	reddish black (10R 2/1) peat; D3; abundant living roots; plant remains a few dead roots unidentified; weakly developed fine and very fine granular structure; abrupt wavy boundary;
9 in.	black (5YR 2/1) peat, slightly silty at the base of the horizon, soapy; D6; abundant live roots; plant remains twigs and small branches almost completely carbonised, many small lumps of carbon present; irregular smooth boundary; 6290 ± 110 years B.P. by C14 determination (Messrs Fergusson and Rafter, pers. comm.)
10 in.	brown to dark brown (7.5YR 4/2 to 3/2) silt loam; firm; massive with a suggestion of a weak fine granular structure; many dark streaks of carbon mark root channels; many living roots; few distinct fine light yellow, greyish green and red brown spots mark less weathered patches; between this horizon and the one above is a compact layer of hardened brown silt loam which breaks out in lumps;
on	dark olive grey and dark reddish brown (5Y 3/2 and 2.5YR 3/4) weathered rock (fine grained olivine basalt).

INTERNODE NUMBERS OF NEW ZEALAND RED CLOVERS, AS INFLUENCED BY VARIETY, TIME OF CLOSING FOR SEED AND DATE OF FLOWERING

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(*Received for publication, 23 March 1960*)

Summary

Two red-clover varieties, cowgrass, and the later-flowering Montgomery, are certified in New Zealand. Counts of stem internodes can be helpful in distinguishing these varieties or detecting contamination of one in the other, but there are limitations to the use of this method.

The range of internode numbers is normally different for each of the two varieties, but there is often considerable overlapping. Time of shutting for seed and time of flowering, are sometimes associated with various levels of internode number that can render uncertain varietal identification by this method. Ease and accuracy of identification may vary with district and season.

Introduction

In New Zealand there are two varieties of red clover (*Trifolium pratense*) in common use, cowgrass and Montgomery. Growth of cowgrass commences early in the spring and flowering is also early, while Montgomery is later in both characters.

For general pasture use these clovers are often sown together, but for seed production or special pastures they are sown separately, and purity of type is essential. In practice the possibility of contamination is a very real one. On farms there are often paddocks of each variety present at the same time, and the carry-over of hard seeds from one crop to another, the spread of seed by stock or machinery, and inter-pollination between adjacent crops, can all lead to mixing of type. Thus it is essential to be able to distinguish pure stands of each variety from those that are contaminated one with the other.

The New Zealand Department of Agriculture, in its seed certification scheme, has relied on two methods for detection of contamination in red clover. The first of these is inspection of the growing crop in the spring. The second involves a plot test at the Grasslands Division of the Department of Scientific and Industrial Research, using seed samples from the inspected crops. In these plots an accurate identification of each variety is not possible until the early spring a year after sowing. Thus the time from crop harvesting until final plot results are available is at least sixteen months, and in this interval the seed from the crop will usually have been sown elsewhere. An earlier result would help to stop the spread of contaminated seed.

Both the plot testing technique and the field inspection of the crop rely on the growth of cowgrass early in the spring, while Montgomery

is still inactive. Under ideal conditions of climate and management, good results are possible from the field inspection as in the large area even a small percentage of cowgrass can be seen. However, under some conditions of climate and management the cowgrass growth is not distinctive, while if paddocks are under grazing at the critical time of differential growth, the spring detection of contamination is often impracticable.

Another method for detecting contamination of one variety by the other, that may be useful in New Zealand, is the comparison of internode numbers on red-clover flowering stems. Hawkins (1953) reviewed reports from Lissitzyn (1925) and Golubev (1951) showing that, in red clover, internode numbers were associated with plant types. Hawkins also, from evidence he had collected over a number of seasons, concluded that by internode counts alone, he would differentiate between numerous varieties of red clover and even between mixtures of these. This led to a survey of the numbers of internodes of red clover crops in different parts of New Zealand, and these results were compared with those given by plot tests of samples of harvested seeds (McNeur unpublished report).

From experience over four years, it is clear that the number of internodes in cowgrass seed crops is usually very stable and within the range 5 to 12, though occasionally this may be widened slightly. Montgomery crops often give characteristic count patterns with a minimum number of 12 or more and a maximum over 30, and in such a crop any cowgrass plants can be readily identified by their internode number. However some crops were found that had all internode numbers in the range 8 to 15, even though these crops were later verified by plot test as pure Montgomery. Because of the difficulties in obtaining accurate records of management of these crops, the present trial was laid down to give some definite information on the effect of closing for seed, and of date of flower production, on the number of internodes on flowering stems in the crop.

Materials and Methods

Nucleus stock-seed areas of both New Zealand cowgrass and New Zealand Montgomery red clover, situated at the Crop Research Division, Lincoln, were used, with three replications of six closing dates for each variety. The first closing date was 12 November, thence plots were closed at two-weekly intervals until 21 January. Plot size was 10 ft by 10 ft with a 4 ft pathway between blocks. After the start of the trial, plots not already closed were mown every two weeks to simulate grazing conditions until the time of closing. Plots were examined at weekly intervals, and from the start of flowering on the first plots some terminal buds that were just breaking into flower were labelled to show the week during which the flowers on that stem first opened. The internodes on the marked stems were later counted and recorded. Also, using the labelled heads as a guide, other stems were sorted to the week of flowering, and the counts of these were included in the totals. The main counting took place in mid February when approximately 100 flowering stems were taken at random for each of the first four closing

dates. At this time there were insufficient flowering heads available for the last two closing dates, so internode counting was carried out each week on stems from these two treatments until the paddocks were harvested in mid March.

The following technique has been adopted for counting the internodes. A stem bearing a terminal flower, or seed head, is pulled from the plant so that it comes away complete from the crown. The terminal flowerhead is essential, as when this has formed the number of internodes on the main stem is finalised. All internodes that can be dis-

Fig. 1.—Sample stems from cowgrass and Montgomery plants.

tinguished are counted, regardless of their length, the count starting at the base and moving up to the terminal head. Under New Zealand conditions there is usually a group of very short internodes, often ten but sometimes over twenty in number, at the base of the stem of Montgomery plants (Figs. 1 and 2), but if these are disregarded the remainder of the stem may be very similar to that of cowgrass. Such a group of many short internodes at the stem base has not yet been found by the author on any stems from cowgrass plants grown under farm management, but it is sometimes absent also from stems of Montgomery plants. Thus, while the presence of these short internodes appears to be a positive identification of Montgomery, their absence does not identify the plant as cowgrass.

Fig. 2.—Close view of base of typical Montgomery stem.

Results

Closing Dates and Number of Internodes

Cowgrass. The effect of closing date on the number of internodes of cowgrass, is shown in Table 1.

TABLE 1. Closing Dates and Number of Internodes of Cowgrass

Treatment	Closing Date	Number of Stems	Mean and SE	Range
1	12.11.57	94	7.47 ± 0.16	4–14
2	26.11.57	109	7.67 ± 0.15	3–15
3	10.12.57	111	7.59 ± 0.14	4–17
4	24.12.57	95	7.40 ± 0.16	4–11
5	7. 1.58	138	7.46 ± 0.13	5–10
6	21. 1.58	120	7.35 ± 0.14	4–11

Closing date produced no significant differences between the mean numbers of internodes.

Histograms for treatments 3 and 6 are shown in Fig. 3. These patterns are typical of those normally found for cowgrass crops. The two high counts in treatment 3 are almost certainly from Montgomery contamination and show how such contamination may be detected.

Montgomery. The effect of closing date on the numbers of internodes of Montgomery red clover is shown in Table 2.

TABLE 2. Closing Dates and Number of Internodes of Montgomery

Treatment	Closing Date	Number of Stems	Mean and SE	Range
1	12.11.57	103	18.9 ± 0.5	8–32
2	26.11.57	92	19.0 ± 0.6	8–33
3	10.12.57	92	19.0 ± 0.6	8–31
4	24.12.57	97	18.6 ± 0.5	9–31
5	7. 1.58	123	13.7 ± 0.5	6–33
6	21.1.58	134	13.3 ± 0.5	5–33

Analysis of variance showed that the mean numbers for treatments 5 and 6 were significantly lower than those for all other treatments.

The two histograms in Fig. 4 show the patterns for treatments 2 and 6. That for treatment 2 is typical of many Montgomery crops, though lowest numbers are often higher than in this instance. The pattern for treatment 6 shows the effect of the later closing, the peak of the histogram being at the lower end of the range.

Flowering Dates and Number of Internodes

Cowgrass. The correlation coefficients (r), relating flowering week (i.e., number of weeks from start of flowering), and number of inter-

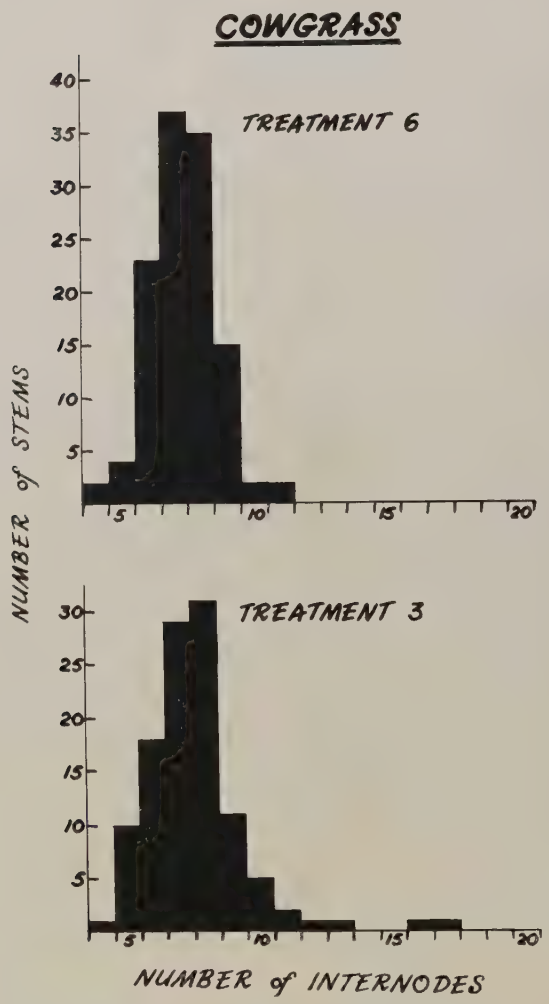

Fig. 3.—Histograms showing patterns of internode numbers from two cowgrass treatments.

nodes, are shown in Table 3, together with estimates (b) of the effects of one week's delay in flowering on the number of internodes. These estimates are the regression coefficients of number of internodes on flowering week, obtained by fitting linear regressions to the data. The tests for significance are the same for both (r) and (b).

To test whether the relationship between flowering week and the number of internodes was affected by closing date, the heterogeneity of regression was examined, which gave an "F" ratio of 3.26 ** (5; 655

TABLE 3. Correlation and Regression Coefficients Relating Flowering Week to Number of Internodes in Cowgrass

Treatment	r	Significance Level	b
1	+ .315 ± 0.99	* *	+ .23 ± .07
2	+ .146 ± .096	N.S.	+ .12 ± .07
3	+ .126 ± .095	N.S.	+ .12 ± .09
4	+ .545 ± .087	* *	+ .48 ± .08
5	+ .210 ± .084	*	+ .08 ± .03
6	+ .128 ± .091	N.S.	+ .08 ± .06

d.f.). This result was clearly due to treatment 4, which had fewer weeks of flowering than any other treatment, and a retest after the deletion of this treatment gave a non-significant "F" for the remainder. When these five remaining treatments were amalgamated, the average regression coefficient within the treatments was + .122 ± .028 **. This means that after the deletion of treatment 4, there remained a significant relationship between flowering week and number of internodes, and this was unaffected by the date of closing for seed. It will be seen from these figures that a normal flowering span of even 8 to 10 weeks would be associated with an increase of only one in the mean number of internodes.

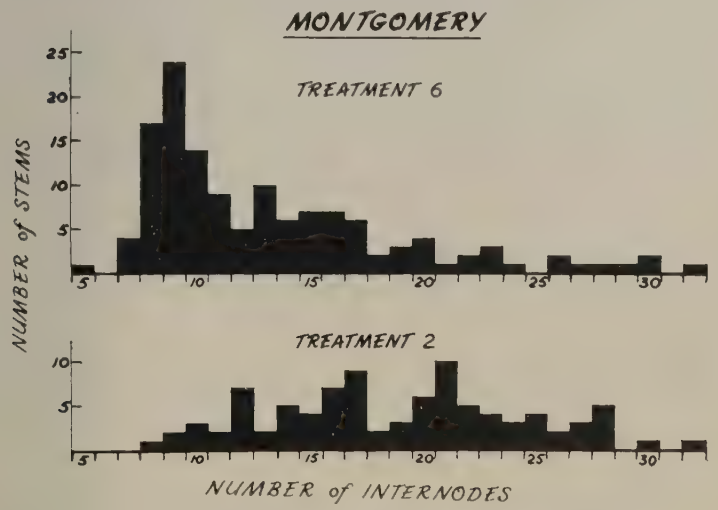

Fig. 4.—Histograms showing patterns of internode numbers from two Montgomery treatments.

Montgomery. The correlation coefficients (r) relating flowering week and number of internodes, are shown in Table 4, together with estimates (b) of the effects of one week's delay in flowering on the numbers of internodes.

TABLE 4. Correlation and Regression Coefficients Relating Flowering Week to Number of Internodes in Montgomery Red Clover

Treatment	r	Significance Level	b
1	+ .473 ± .088	* *	+ 1.14 ± .21
2	— .041 ± .105	N.S.	— 0.13 ± .33
3	— .085 ± .105	N.S.	— 0.21 ± .25
4	+ .021 ± .103	N.S.	+ 0.07 ± .35
5	— .419 ± .083	* *	— 0.86 ± .17
6	— .597 ± .070	* *	— 1.46 ± .17

These results show that in treatment 1 there was a very marked positive relationship between flowering week and the number of internodes, with a reversal to very strongly marked negative relationships in treatments 5 and 6. Thus in treatment 1, the delay in flowering was associated with an increase of one internode for each week of delay, while in treatments 5 and 6 the same delay in flowering was associated with a decrease of one internode. This indicates that, after some undetermined date, Montgomery red clover flowered with progressively lower numbers of internodes.

In Fig. 5, the numbers of internodes for Montgomery treatments 1, 3, and 6 are shown with the corresponding week when flowering took place. This illustrates that for treatment 1 the numbers of internodes increased with later flowering, while for treatment 6 the numbers decreased with later flowering. This decrease was particularly marked during the last few weeks in treatment 6, when nearly all counts were within the normal cowgrass range (Fig. 3).

Discussion

Table 1 shows that, for cowgrass, the date of closing areas for seed had no effect on the mean number of internodes. Thus internode numbers would not be affected by the previous management of the crop, whether cut or subject to grazing up to any closing date. From Table 2, it is seen that, for Montgomery, there was no significant difference between any two of the mean internode counts from areas closed between 12 November and 24 December, but that both the areas closed during January produced significantly lower mean internode numbers than did the earlier-closed areas. These two later treatments, 5 and 6, originally gave only 66 and 71 suitable stems respectively, and significant differences were obtained between these two treatments and the remainder. Extra counts were taken from treatments 5 and 6 for several more weeks, to ensure that the shorter period of flowering at the first counting had not caused the significant differences found. These extra counts did not, however, affect the finding.

A comparison of Tables 1 and 2 shows that the mean internode number for any cowgrass treatment was very different from that for any Montgomery treatment, even though certain of the Montgomery counts were inside the normal cowgrass range. Thus in this trial at least, it

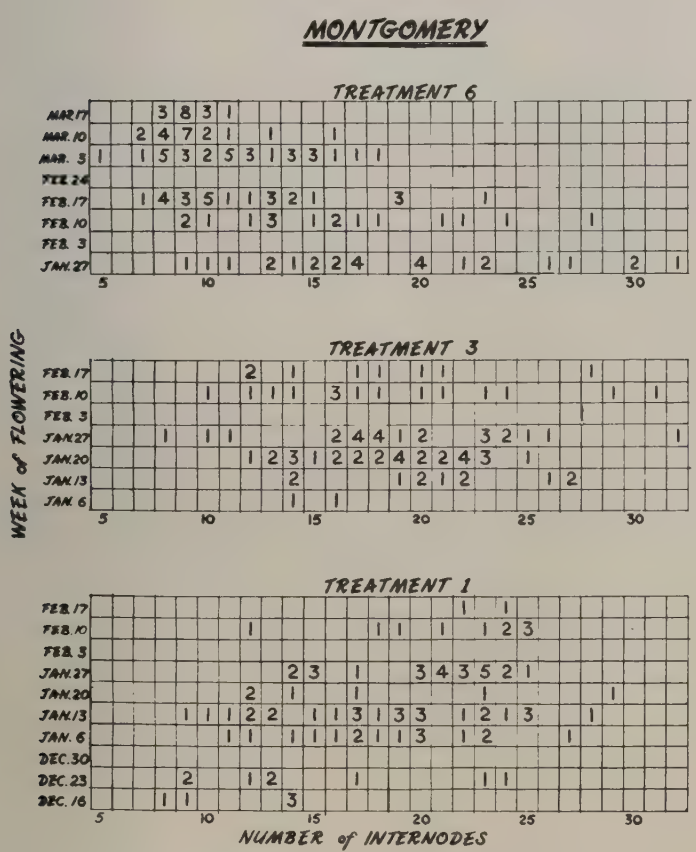

Fig. 5.—Internode numbers from three Montgomery treatments, expanded to show individual numbers for different flowering weeks.

was possible to identify the variety of red clover present in any plot, from an examination of the internode numbers. It can be seen, however, by an examination of Fig. 3 and Fig. 4, that a pattern similar to that for Montgomery treatment 6 could be produced by mixing data from Montgomery treatment 2 and from any of the cowgrass treatments. Thus the peak of low counts found in Montgomery treatment 6 could be due either to cowgrass contamination or to "low count" Montgomery stems. Table 4 and Fig. 5 show that in the present instance the peak of low counts for Montgomery treatment 6 was due to later-flowering stems, but the example does make obvious one of the difficulties in detecting contamination of red clover varieties by the use of internode numbers. In practice it is recommended that when sampling an area of Montgomery for internode counting, any late-flowering stems should be avoided. This is important especially in crops where the

main flowering is finished and the crop perhaps even mature, but where the late rains have caused regrowth from plants, as if this precaution is not taken some of these regrowth stems may be wrongly identified as cowgrass on account of their low internode number.

As shown in Tables 3 and 4, and in the remarks regarding the calculations from these tables, it is clear that cowgrass behaves differently from Montgomery in regard to the influence of an extension in flowering time and the resultant numbers of internodes. Cowgrass has shown the tendency for counts to become higher with later flowering, regardless of closing date. Montgomery, on the other hand, changed from having an increase in internode number with later flowering in early-closed crops to a marked decrease with later flowering in late-closed crops. The rather anomalous behaviour of cowgrass treatment 4, where there was a more definite increase in number of internodes with late flowering, is not readily explained, and the fact that there were fewer weeks of flowering for this treatment than for any other does not appear to offer an explanation.

It can be concluded from this trial that, when crops of red clover have been closed for seed early in the season, any high percentage of contamination of either variety by the other will be detected by internode numbers. If, however, closing has been delayed until late in the season, the use of numbers of internodes for variety identification would be unreliable. The critical date for this changeover has not been determined but in this trial it was somewhere between 24 December and 7 January. These dates, however, are applicable only to the particular district and season in which the trial was conducted, as there is evidence that internode numbers are affected by climatic conditions at the time of growth.

Hawkins (1953) found that he could use numbers of internodes to distinguish between crops of early- and late-flowering red clovers even though they had been grazed up till "early June" (Northern Hemisphere), but he does not list experience with crops closed later than this, at dates comparable with those when we experience difficulty in using the method.

Our experience would indicate that internode numbers can be used for distinguishing between crops or even individual plants of New Zealand certified cowgrass and Montgomery red clover. However, as closing dates become later, increasing care must be taken in interpreting results, until with very late closing the method cannot be expected to give accurate results.

This final merging of internode numbers as closing dates get later leads one to agree with Lissitzyn (1933), when he states "Neither of these local types (of red clover) is completely or sharply demarcated from the other, but both are mixtures, the extremes of which overlap one another and become indistinguishable from one another in their biological characters."

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EAR EMERGENCE IN PERENNIAL RYEGRASS AS AFFECTED BY DIFFERENCES IN LIGHT AND TEMPERATURE BEFORE EAR INITIATION

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Summary

The effects of differences in daylength and temperature, before ear initiation, on subsequent emergence in perennial ryegrass selections were studied in the glasshouse. When no artificial light or heat was used, prolific and uniform emergence was observed. Of seven other combinations compared, uniform but much earlier emergence was obtained from only that treatment where the natural sequence of events, cold short days followed by long warm days, was accelerated. A number of interactions occurred between the other treatments and the selections used.

Introduction

Attainment of the "ripe-to-flower" stage, that is, of the capability for initiation of reproductive growth, is largely determined in higher plants by day length and temperature, and so is time and degree of inflorescence emergence after the change-over from the vegetative stage has occurred. The processes have been investigated in the ryegrasses specially from the point of view of vernalisation, by Cairns (1940), Wycherley (1952), Wit *et al.* (1956), Cooper (1951, 1957) and Fejer (in preparation). As a result of these investigations it is clear that there is a varying cold requirement in ryegrass varieties before the "ripe-to-flower" stage can be attained, and that this requirement can be partially replaced by short days. There is also a variable long-day requirement before actual ear emergence can take place. Natural light can be replaced by artificial light of low intensity to force "ripe-to-flower" plants into ear emergence.

It should then be possible, by suitable manipulations of these factors, to bring any ryegrass variety to flower at any time of the year, to assist genetical and plant breeding trials. However, only limited information has been obtained on the practical aspect in ryegrass (Sprague 1948). Some data are available on the effects of temperature and light on ear emergence from a glasshouse experiment, conducted on vegetative development (Fejer 1955), and are reported here.

Material and Methods

The perennial ryegrass (*Lolium perenne* L.) plants were from a collection of plants made from old-established pastures in New Zealand. They were selected for two generations for high or low production, ((HP2) and (LP2)), and high or low tiller number ((HT2) and (LT2)). The plants were produced by sibbing, and included outcrosses (X) and inbred progenies (S) of perennial ryegrass, together with the original unselected line. They were taken from the field on 9 April

1954, and were cloned. Eight cuttings of each of 24 plants used were grown singly in 6 in. pots during the winter of 1954, two in each of four glasshouses, which combined long days, artificially extended to 16 hours, or normal short days, with warm (approx. 70°F day, 50°F night) or cold (approx. 60°F day, 40°F night) temperatures. Mercury vapour lamps interspersed with incandescent lamps, of a total strength of 600 W, were used during the extended part of the day and the light was reflected to the plants from a white reflector about 6 ft above the pots. To balance the shading effect caused by this reflector, the glasshouses providing normal days were whitewashed at the roof and walls, with the result that in the winter the relative light intensities at plant level, compared to outdoors were approximately 25% by day in all glasshouses, and approximately 12% during the extended part of the day. Warm glasshouses were heated by electric fan-heaters controlled by thermostats set at 70°F. This heating system was insufficient to hold the temperature at 70°F on the colder winter nights. Glasshouse temperatures on such nights varied between 40° and 60°F as registered by thermographs. Also, during the spring months, there were times when differences in temperature between heated and unheated glasshouses were small.

After three vegetative harvests at monthly intervals (cutting height 1 in.), on 4 August one plant from each clonal pair in the four combined treatments was moved into another of the four glasshouses, giving the following eight treatments:

1. Long days, warm temperatures — LD/W
2. Long days, warm temperatures, changed to normal days, cold temperatures — LD/W-ND/C
3. Long days, cold temperatures — LD/C
4. Long days, cold temperatures changed to normal days, warm temperatures — LD/C-ND/W
5. Normal days, warm temperatures — ND/W
6. Normal days, warm temperatures changed to long days, cold temperatures — ND/W-LD/C
7. Normal days, cold temperatures — ND/C
8. Normal days, cold temperatures, changed to long days, warm temperatures — ND/C-LD/W

Dates of ear emergence were recorded on the day when the first ear started to emerge from the leaf sheath. The height of that head was recorded at flowering. The total number of emerged heads was also recorded. The time from emergence to flowering ranged from 11 to 20 days. All emerged ears flowered and no further sign of ear initiation was visible on 17 December 1954 when the trial was terminated. On this date all plants were harvested and top root ratios determined from the dry weight.

Results and Discussion

Table 1 shows the dates of ear emergence and plant height and number of ears at flowering, for each of the progenies used.

TABLE 1. DAYS TO EMERGENCE FROM CHANGE-OVER OF TREATMENTS AND NUMBER AND HEIGHT OF FLOWERING STEMS

Progeny		No. of Plants	LD/W	LD/W–ND/C	LD/C	LD/C–ND/W	ND/W	ND/W–LD/C	ND/C	ND/C–LD/W
Sibs	HP2	2	*	*	69 ± 12	*	**84**	58 ± 5	93 ± 3	36 ± 2
	HT2	2	*	106 ± 7	48 ± 12	75 ± 21	95 ± 6	54 ± 5	85 ± 3	34 ± 2
	LP2	2	*	*	48 ± 12	**47**	96 ± 6	52 ± 5	87 ± 3	35 ± 2
	LT2	2	**104**	**119**	55 ± 12	**42**	87 ± 6	51 ± 7	83 ± 3	34 ± 2
Serfings	HS2	3	**70**	108 ± 6	38 ± 9	**38** ± 21	**124** ± 6	67 ± 4	88 ± 2	39 ± 1
	LS2	3	*	118 ± 6	44 ± 9	80 ± 21	101 ± 5	52 ± 4	87 ± 2	35 ± 1
Outcrosses	HX2	3	**27**	106 ± 6	38 ± 9	43 ± 17	88 ± 6	61 ± 4	85 ± 2	36 ± 1
	LX2	3	*	**116** ± 7	66 ± 9	77 ± 17	**92**	59 ± 5	87 ± 2	35 ± 1
Unselected line		4	**68**	**115** ± 7	48 ± 8	**34** ± 21	90 ± 4	56 ± 3	89 ± 2	34 ± 1
Overall		24	**66**	**112** ± 3	50 ± 3	**56** ± 8	**96** ± 2	57 ± 1.4	87 ± 0.7	35 ± 0.4
No. of plants not flowered			19	8	—	7	3	—	—	—
Head number			2	14 ± 5	13 ± 2	4 ± 0.7	10 ± 0.7	18 ± 1.6	45 ± 2.7	15 ± 0.9
Height of flowering stem (cm)			57	51 ± 2	59 ± 2	34 ± 2	47 ± 1	67 ± 2	75 ± 2	56 ± 1

* indicates no plants emerged.

Bold type indicates "groups contained one or more plants which did not emerge". As such plants were omitted from the analysis, means in bold type should be treated with caution.

In dates of ear emergence, there were very strong differences in the reaction of the individual plants to the different treatments, but, though cuttings of the same plants were used throughout, confidence limits cannot be calculated as a plant was represented by only one cutting in each treatment. On the other hand, overall differences between the treatments were significant in several cases. Thus, the plants in the ND/C-LD/W treatment were the earliest, and cuttings of the same plants in the LD/C, LD/C-ND/W and ND/W-LD/C treatments were also significantly earlier than in the other treatments. For the other treatment combinations, plants in the continuous LD/W treatment were significantly earlier than in the LD/W-ND/C treatment, although the extent of flowering was much less in the LD/W treatment.

The unheated glasshouse with normal daylength (ND/C) had conditions that were nearest to those in the open. The time of emergence of plants in this glasshouse coincided with that of the same line of plants in the field and showed remarkable uniformity (s.e. per plant $\pm$ 3.5 days). In the ND/C-LD/W treatment the uniformity of ear emergence was similar to that of ND/C (s.e. per plant $\pm$ 1.7 days). The ND/C-LD/W treatment is commonly used to produce early flowering and the efficiency of this technique is evident from Table 1.

The means of individual treatments show that there were relatively few significant differences in date of ear emergence between high and low selections or inbred and outcrossed material, probably owing to the low number of plants used. In the LD/C treatment there was a difference ($p = 0.10$) between the outcrossed progenies, the high selection being earlier. This was unusual as emergence in the high selection is usually later than in the low selection. In the ND/W treatment, the low selfings were significantly earlier than the high. Also, the high selfings were significantly later than all other progenies. In the ND/W-LD/C treatment, the low selfings were again significantly earlier than the high, and, taken over all progenies, the low selections were significantly earlier. In the ND/C-LD/W treatment, the differences recorded above in ND/W were also found, and, although small, were significant because of the low variability. In the ND/C treatment, both the low-tillering and high-tillering sibs were significantly earlier than the high-producing sibs.

It was considered that at the time of the shift in the conditions, all progenies exposed to natural cold should have received sufficient cold for ear initiation. This has been substantiated by the fact that all plants emerged in the ND/C-LD/W treatment. On the other hand, the continuous LD/W treatment was the most detrimental to emergence, as the de-vernalising effect of heat was combined with that of long days. This is in conformity with the views of Went (1954). Emergence was delayed or prevented in the LD/W-ND/C treatment. This stresses the importance of the time sequence of the treatments.

In the unshifted ND/W treatment there were only three progenies with non-emerging plants. While all plants received a certain amount of cold before the main experiment started in June, and heating was insufficient to maintain night temperature at 50°F on a few very cold nights, it seems likely that the effect of short-day induction reported by

Cooper (1957), associated with reduced light intensity, promoted emergence in the ND/W treatment.

In the LD/C-ND/W treatment there were 5 progenies with non-emerging plants, 3 of these being full-flowering in the unshifted ND/W treatment. As there was full flowering in the unshifted LD/C treatment, it is clear that there was an interaction between the conditions, the responses varying with progeny. For example, the low-producing outcrossed plants (LX2) showed incomplete emergence in ND/W, the low-producing and low-tillering progenies (LP2, LT2) and the unselected line showed incomplete emergence in LD/C-ND/W, while the high-producing sibs and selfings (HP2, HS2) did not emerge completely in either treatment. On the other hand the high-producing selfings (HS2) showed complete emergence in the LD/W-ND/C treatment, while all the other progenies mentioned in the previous sentence emerged incompletely. Evidently the various combinations of treatment factors strike different balances between vernalisation and de-vernalisation in different progenies.

In height and number of emerged heads at flowering, ND/C conditions were clearly optimal. In the ND/W treatment, the low variability allowed significant differences to be established. These figures are not shown in the table, but, generally, head number was higher in high-producing progenies and flowering shoots were longer in low-producing progenies. The effect of inbreeding depression was shown in the short flowering shoots of the sibs and the selfings. However, the environmental effects overshadowed the genetical effects, as is shown by the very low number of heads and short stems in the LD/C-ND/W treatment.

The top/root ratios are summarised in Table 2.

There were significant differences due to treatments, and they were often similar to differences between treatments in flowering characters, e.g., in the ND/W-LD/C and ND/C-LD/W treatments top/root ratios were relatively high as were head number and height. However, in the ND/C and LD/C treatments, where all plants flowered, the top/root ratios were significantly lower, but still higher than those in the flowering plants in LD/W and LD/W-ND/C. As shown in Table 2, this was not a simple reflection of the number of non-flowering plants under a particular treatment, as there was little difference between the top/root ratios within any treatment.

The high top/root ratios in the ND/W-LD/C and ND/C-LD/W treatments showed an interaction between the high and low selection lines. Taken over all progenies, the high ratio (3.4) in ND/W-LD/C was mainly due to the particularly high values of the progenies of low selection origin, (4.5), against the mean of the progenies of high selection, (3.0), whereas there is a reversal under the ND/C-LD/W condition, the same high ratio being due to the high values of the high selection progenies, (3.9), while the mean value of the low progenies was 3.1.

Conclusion

For practical purposes, very uniform and early flowering can generally be achieved in perennial ryegrass plants by growing them at

TABLE 2. TOP/ROOT RATIOS OF DRY WEIGHTS, 17 DECEMBER 1954.
(Mean values of progenies shown in Table 1)

Mean values of	LD/W	LD/W–ND/C	LD/C	LD/C–ND/W	ND/W	ND/W–LD/C	ND/C	ND/C–LD/W
Flowering plants	1.5 ± 0.4	1.1 ± 0.1	1.7 ± 0.1	1.6 ± 0.2	2.3 ± 0.2	3.1 ± 0.2	2.3 ± 0.1	3.1 ± 0.3
Non-flowering plants	1.8 ± 0.4	0.9 ± 0.1	—	2.2 ± 0.5	2.2 ± 0.2			

first in the normal short days of the winter under cold conditions, and later in heated glasshouses where the daylength is artificially extended to 16 hours by light of low intensity. The treatment change-over can take place in mid-winter. However, certain differences can be expected in the response according to the genetical make-up of the plant material used.

If production of a high number of heads is aimed at, a longer period of short days and cool temperatures, as provided under the gradually increasing day-length and temperature of natural days after mid winter, is preferable. It appears that this leaves time for the plants to develop a higher number of tillers under favourable conditions and also a stronger root-system, as shown in the top/root ratios. The final height of the seed head is also greatest under this condition.

Acknowledgment

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FERTILITY RESPONSES IN EWES TREATED WITH THYROXINE

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Summary

The fertility results from 860 control and 1233 treated mixed-aged ewes implanted with l-thyroxine are presented.

On a lambs produced/ewes mated basis, the total figures covering the three breeding seasons 1955-57 inclusive, show an increase of 9.5% in favour of the treated ewes. The fertility responses appear to be very sensitive to the rate of absorption of thyroxine.

The effects of different thyroxine dose levels and two-tooth versus mature ewe responses, are discussed in relation to the fertility of the animals concerned.

Introduction

The practice of flushing ewes in order to stimulate higher lambing percentages has been recognised and commented upon by many workers throughout the world from time immemorial.

Various interpretations and suggestions as to the mode of action have been made from the time Aristotle first appears to have observed responses in the fertility of sheep associated with abundant food, as described by Marshall (1952).

One of the earliest attempts to define flushing was that of Marshall and Potts (1921) who showed that where ewes were able to gain 7 pounds a week throughout mating, an approximate increased lambing of 18% was recorded. Underwood and Shier (1941) produced further evidence that gain in live weight was necessary, when they obtained a 20% increased lambing from flushed ewes which gained 15 lb when compared with control ewes which lost 7 lb during tupping.

Wallace (1951), in his trials at Ruakura, supplies additional evidence indicating that increased lambing figures can be obtained from ewes tupped during a period when they were gaining live weight to the extent of 15-17 lb per animal.

The results from these workers all emphasise the point that the one common factor in these experiments is the rise in live weight prior to and during the mating period. This appears therefore to be an essential factor if an increased lambing percentage is to be obtained.

Further evidence supporting this view is provided by Clark (1934) who in the course of his experiments investigating a slightly different aspect of the same problem, showed that flushing involving a gain in live weight increased the ovulation rate provided the ewes were not in high condition to start with. This introduced the possibility that gain in weight itself does not necessarily indicate a high ovulation rate, a point which as Fraser (1949) points out may help to explain some

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of the indifferent results obtained from flushing caused through the ewes being in too high a condition at the commencement of the process. As a result, it is now considered to be quite a normal procedure to put ewes deliberately on a sub-maintenance level of nutrition in order to make them lose wight preparatory to flushing, a practice which is commonly followed in the field of practical animal husbandry with beneficial results.

Now, although there have been numerous successful experiments conducted in different parts of the world, all clearly demonstrating that either an increased lambing percentage or an increase in the ovulation rate may be obtained, no direct evidence as to the mode of this response has yet been presented. Hammond (1942) suggests that the effect of flushing is to increase the pituitary activity and in particular the anterior pituitary hormone output, this in turn stimulating an increased ovulation rate. This view seems to be a rather difficult one to substantiate experimentally. However, it appears to be the only feasible explanation, in so far as ovulation is so essentially a function of the endocrine system.

There seems little doubt that the one common measurable factor associated with all these reported increases in lambing is the gain in live weight during the mating period. In connection with the experiments conducted at Lincoln College using l-thyroxine implant pellets to stimulate the rate of growth of wool, loss of live weight, followed by a gradual recovery, had been observed in thyroxine-treated ewes kept in pens, on a standard fixed maintenance ration (Hart 1955). The maximum live-weight loss was also noted to occur usually between 14 and 21 days following implantation, after which there was a gradual recovery of live weight without any alteration having been made in the ration. From these observations it appeared possible that through the use of the hormone one might be able artificially to put the animal into a state of gradually increasing live weight rather similar to that achieved by use of the more conventional flushing procedure. The question then arose as to whether if the ewes were mated during this period an increased lambing percentage would be obtainable, as with normal flushing. Accordingly, wherever possible, tupping times were related to implanting, and records obtained of the subsequent lambing, in most of the trials carried out during the period 1955-57 to increase wool growth responses, results of which have been already published (Hart 1957). The purpose of this paper is to present the data relating to the reproduction responses obtained from these trials.

Experimental Methods

Implanting. As previously described (Hart 1957) this was done subcutaneously at a point behind the shoulder, about two inches down from the centre line of the back. Whilst at the time the site was not considered specially important, it is thought now that, for the purposes of obtaining the requisite pattern of live-weight change necessary to engender a reproductive response, the site and all other factors affecting the hormone absorption rate and live-weight change are of considerable importance.

Lamb recording. This was carried out as the ewes lambed. In the case of flock ewes, treated and control ewes were identified by different-coloured branding paint marks, stud ewes of course all being capable of individual identification by means of ear-tags. Daily shedding off of lambed ewes plus their lambs from the ewes yet to lamb, was the procedure adopted in all trials, it being thus possible to record all lambs born during each twenty-four hour period for each of the treatment groups. Where there was any doubt of positive identification of ewes and lambs at lambing, these were excluded from the results. This, coupled with deaths, assists in explaining apparent discrepancies in ewe numbers in some of the tables. Also, as a correction for analysis purposes, all dry ewes in each group were credited with one lamb at the expense of the multiple birth group.

PROCEDURES AND RESULTS

1955 Experiments

One hundred five-year-old Border Leicester-Halfbred cross ewes were randomised into two groups of fifty ewes. Both groups were identified by ear marks and paint marks on the back.

The group for treatment was implanted on 18 February with 90 mg of thyroxine per ewe.

Both groups of ewes were then given the same treatment, being run with the remaining ewes on the property and subjected to normal fat-lamb management of that farm, flushing of a limited nature only being possible that year.

The rams were put out with the ewes on 1 March, eleven days after implantation, and tupping proceeded normally.

The lambing figures for the treated and untreated groups are shown in Table 1, the increased number of twin births obtained from the treated group being very highly significant.

TABLE 1. LAMBING RESPONSE FROM MATURE BORDER LEICESTER-HALFBRED CROSS EWES, 1955

Treatment	Ewes to Ram	Lambs Born	%	Ewes with Single Births	Ewes with Multiple Births
Control	50	52	104	42	5
Implanted 90 mg thyroxine	50	69	138	27	21***

***P = < 0.01

1956 Experiments

A. *Ovulation Response*

One hundred and forty aged Corriedale ewes were randomised on a weight basis into two groups, each ewe being individually numbered.

The experimental group were all implanted with 90 mg of thyroxine and then both groups were grazed and fed as one mob. Supplementary feeding of hay and concentrated sheep nuts were used as necessary, and adjusted so as to maintain the controls as nearly as possible at a constant live weight until slaughtered.

The live weights were obtained at the commencement of the trial at the time of implantation, and again at the conclusion, just before each animal was slaughtered, check weighings being made as necessary of selected ewes, for ration adjustment purposes. Average weights of the groups are shown in Table 2.

TABLE 2. AVERAGE GROUP LIVE WEIGHTS 1956

Treatment	Commencement of Experiment lb	Slaughter lb	Difference lb
Control	123.6	123	—0.6
Implanted	126.4	119.1	—7.3

Fertile raddled rams were run with all the ewes as one group, from the tenth day after implantation onwards, each ewe being identified by means of the number paint branded on her mid-side. Records were kept twice daily of the ewes as they came into oestrus and were served by the ram.

As the ewes were tupped they were removed from the main mob, weighed, and slaughtered within five days of the end of oestrus. The reproductive tracts were removed and a careful laboratory examination conducted. Corpora lutea counts were made and the liberated ova recovered from the oviducts or uteri.

The recovered ova were classified into fertilised and unfertilised and in addition rates of abnormal ova production were recorded. The ova were classified on the basis of the criteria used by Hart (1955) and later accepted as satisfactory by Hart and Dutt *et al.* (unpublished data) in their 1957 investigations.

TABLE 3. OVULATION RESPONSE 1956

Treatment	Ewes Mated and Slaughtered	No. of Ovulations	Ewes with Single Ovulations	Ewes with Multiple Ovulations
Control	65	80	50	15
Implanted 90 mg thyroxine	69	95	43	26*

*P = <0.1

It will be seen from Table 2 that there was definite evidence at the time of slaughter that a biological response in loss of live weight had been induced in treated ewes. Some further evidence of an effect is also indicated by the ovulation response shown in Table 3. Here it will be seen that the maximum possible potential lambing would have been 123% for the controls and 137.6% in the case of the implanted group, representing an increase of 14.5%. Although this appears substantial the difference in the number of ewes having single and multiple ovulations between the two groups reaches a significance of only 0.1 using the test for chi squared.

The 156 ova classified in Table 4, representing a recovery rate of 89% of all ova shed between the two groups, indicate that the thyroxine has had no significant effect on either the number of normal ova fertilised or the number of normal ova unfertilised, but has caused a highly significant reduction in the number of abnormal ova produced.

TABLE 4. OVA CLASSIFICATION 1956

Treatment	Ova Recovered	Ova Fertilised	Normal Ova Unfertilised	Abnormal Ova
Control	68	50	3	15***
Implanted 90 mg thyroxine	88	71 NS	2 NS	5

***P = <0.01

B. *Lambing Response* (Fat-lamb Flock)

This trial was carried out using the commercial fat-lamb flock of 631 mixed-aged Romney and Corriedale ewes at Lincoln College as the source of experimental material.

The management of the flock throughout the period was left entirely to the College Farm Superintendent who attempted, as far as possible, to follow the traditional methods associated with normal fat-lamb production. The only departure from this being in connection with the timing of the implanting date with the date the rams were to be joined with the ewes. The ewes were randomised, for an equal distribution of breed and age, into three groups and implanted on 12 March. Rams were joined with the ewes on 23 March.

The two implanted groups were of similar size, but both smaller than the control group because there was not sufficient thyroxine available at that particular time to equalise all groups for numbers. The two implanted groups were paint branded at different points on the back, whilst the controls were left unbranded, the brands being checked and rebranded where necessary when the ewes were brought in for crutching prior to lambing.

The complete 1956 flock was put through a modified flushing programme only, as feed was short for that season.

At lambing, which was closely supervised twice daily, a complete record was kept of every ewe producing a full-time lamb. This was done by adopting a shedding practice for all ewes lambing so that it was possible to group identify accurately each ewe as she and her lamb or lambs were separated from those yet to lamb.

TABLE 5. Lambing Response of Mature Crossbred Ewes to Thyroxine

Treatment	Ewes to Ram	Lambs Born	%	Ewes with Single Births	Ewes with Multiple Births
Control	262	297	113.3	227	35
Implant 60 mg thyroxine	187	247	132.8	127	60***
Implant 90 mg thyroxine	182	220	126.5	144	38**

***P = <0.01
**P = <0.05

Table 5 gives the results from this trial, the figures being calculated on a basis of ewes mated to the ram thus including all dry ewes as a correction factor for the analysis. This shows that the number of ewes having multiple births in relation to the number having singles is significantly higher in both thyroxine groups than the controls. In addition there is also a significant difference between the 60 mg implant and the 90 mg implant. No significant difference was found in the percentage of dry ewes recorded from each group which were as follows:—

Control	8.7%
60 mg thyroxine	5.3%
90 mg thyroxine	6.6%

Apart from the actual increase in the number of multiple births obtained from both the thyroxine groups, there appears to be a definite change in the pattern of lambing as shown in Fig. 1. This depicts the daily progressive percentage of lambs born on ewes lambing, and it is obvious that whilst the control curve follows a fairly normal rise to a peak plateau, with evidence of a decline setting in towards the end of lambing, both thyroxine groups present an atypical pattern. It is noteworthy that in each of the thyroxine-treated groups the peak percentage occurs at the commencement and slowly declines throughout lambing. The distribution-of-lambing-curves are shown in Fig. 2 and indicate that neither of the treatments has adversely affected the rate at which the mature ewes lambed. The mature ewes thus presented an entirely different lambing pattern from that of the two-tooth ewes, used later by Ross and Lewis (1958).

C. *Lambing Response* (Stud Romney flock)

A similar trial was carried out with some top stud Romney ewes where accurate records were kept and all information was available.

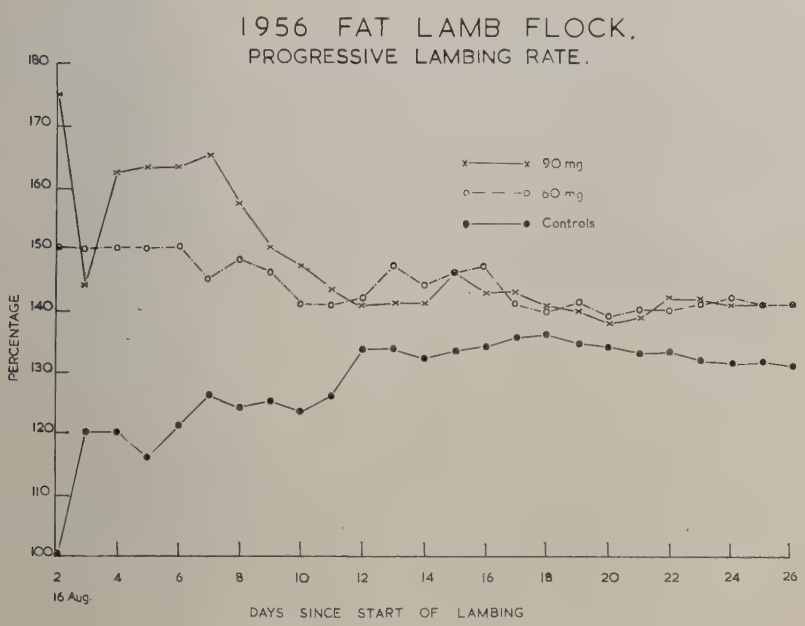

Fig. 1.—Progressive lambing rate of thyroxine-treated ewes at two-day intervals.

The major object of this experiment was to compare the effect of the thyroxine implant on young two-tooth ewes as well as mature ewes (four-tooth and older) under the same conditions. In addition the response of the animals when kept under the optimum conditions normally associated with stud breeding was also a point of interest.

One hundred mature ewes (4-tooth and older) were divided into two groups consisting of 46 controls and 54 treated; two groups of 2-tooths, 61 controls and 55 treated were also included. The two groups for treatment were implanted with 90 mg thyroxine in each ewe as previously described, on 6 March 1956. The normal stud management was followed with the rams being put out with the ewes eleven days later.

Unfortunately owing to the danger of facial eczema the rams and ewes had to be shut up and fed on lucerne hay for a period of six weeks. This appeared to affect the 2-tooths more than the mature ewes and in particular the treated 2-tooths. Normal stud conditions were followed from then onwards until lambing.

At lambing it was possible to identify each ewe by means of her ear tag and the results for both mature and 2-tooth ewes are shown in Table 6. The increased number of ewes having multiple births as compared with those having single births was not statistically significant in either the mature or 2-tooth ewes in this experiment.

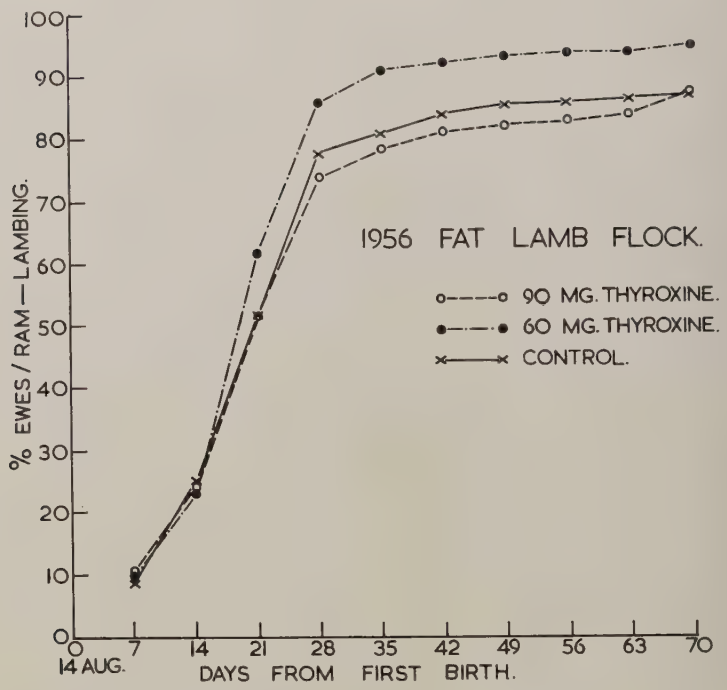

Fig. 2.—Effect of thyroxine on distribution of lambing in 1956 fat-lamb flock.

TABLE 6. LAMBING RESPONSE OF MATURE AND TWO-TOOTH STUD ROMNEY EWES TO THYROXINE

Treatment	Ewes to Ram	Lambs Born	%	Ewes with Single Births	Ewes with Multiple Births
			Mature Ewes		
Control	46	58	126	34	12
Implant 90 mg thyroxine	54	73	135	35	19 NS
			Two-tooth Ewes		
Control	60	64	106	38	13 NS
Implant 90 mg thyroxine	55	52	94	36	8

1957 Experiments

Almost the entire flock of Romney Cross fat-lamb breeding ewes belonging to a commercial farm were used in this trial. All the sheep were treated alike, being managed as one flock throughout until lambing, when they were divided into two flocks each with an equal distribution of treated and control animals. This was done in order to facilitate the accurate collection of records at lambing, and once again the practice of daily shedding off the lambed ewes was adopted in order to assist in this operation.

Implanting was done on 20 February, the mature ewes receiving 60 mg of thyroxine each and the two-tooth ewes 30 mg. The substantial reduction in the dose rate for two-tooths was decided upon after considering the results obtained from the stud two-tooths the previous year (Table 6) and also the 1956 results obtained by Ross and Lewis, and published later in 1958. It was thought that although these were not significant statistically in either case, except the number barren in the experiment of Ross and Lewis, they did indicate that a dose of 90 mg of thyroxine to two-tooths could have been above the level for optimum results and in fact was most probably adversely affecting their reproduction. The mature ewe dose was reduced on the basis that the average live weight of the commercial Romney fat-lamb ewe was considerably lighter than that of the stud Romney and also because the 1956 results had indicated that the 60 mg dose produced a better fertility response than the 90 mg of thyroxine (Table 5).

Southdown rams were turned out with all ewes on 1 March, and as far as could be ascertained tupping proceeded normally. This is also borne out by the lambing distribution curve shown in Fig. 3 which depicts the combined performance of two-tooth and mature ewes in the treated and control groups.

TABLE 7. LAMBING RESPONSE OF MATURE AND TWO-TOOTH ROMNEY CROSS EWES TO THYROXINE

Treatment	Ewes to Ram	Lambs Born	%	Ewes with Single Births	Ewes with Multiple Births
			Mature Ewes		
Control	273	291	106.5	187	52
Implant 60 mg thyroxine	541	619	114.4	299	160***
			Two-tooth Ewes		
Control	104	104	100.0	88	8
Implant 30 mg thyroxine	95	98	103.1	76	11 NS

*** = very highly significant $P < .005$

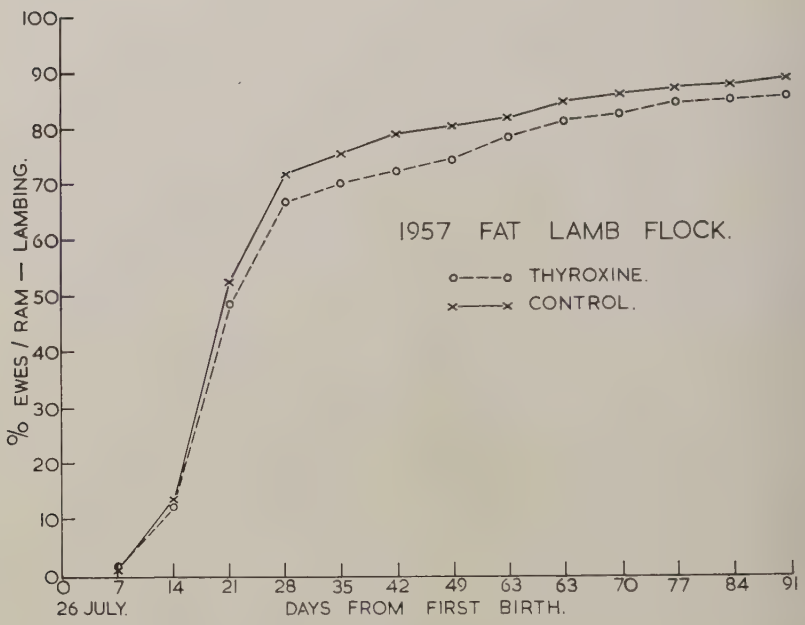

Fig. 3.—Effect of thyroxine on distribution of lambing in 1957 fat-lamb flock.

Details of the performance at lambing of both the mature and two-tooth ewes are given separately in Table 7. The increased numbers of ewes having multiple births in the treated section of the mature group is highly significant, but that of the treated two-tooths is not.

Discussion

From the results obtained in these and other experiments with thyroxine, it is obviously possible to affect the reproductive behaviour of sheep in varying degrees.

In view of the wide disparity of results achieved by various workers who have used thyroxine for this purpose, an attempt is made here to examine critically the data and present some acceptable evaluation of the available information.

As has already been pointed out, our knowledge of the precise reason for the increased fertility of normally "flushed ewes" is far from complete. It has been possible to define in a generalised form the procedure to adopt in order to obtain a response in this field (Wallace 1951), but at the same time there has always been the case where no response has occurred in spite of all the correct procedures having been followed and also where a response has been achieved with no special treatment being attempted. This situation seems to be incapable of being explained for the present and has therefore to be accepted as such.

The results reported from thyroxine have varied considerably, and not all can be satisfactorily explained either by the above situation or by reason of the fact that as in all work of an empirical nature a certain modicum of deliberate "trial and error" methods have to be adopted.

As a result of all the thyroxine studies carried out at Lincoln College, it has been found that of the three major responses measured, wool, lactation, and fertility, the latter is by far the most sensitive and critical in its reaction. Wool and lactation responses are achievable over quite a range in terms of time of implantation relative to any datum point. On the other hand to obtain a fertility response it appears essential that the initial live-weight loss must be achieved before the ewe is actually mated to the ram. Also the fertility period only exists from the time the ewe reaches her maximum live-weight loss, over the early regain period, which is at a slightly faster rate than the later regain period and for a very short period afterwards (Fig. 4). If the ewe happens to be tupped outside these times the chances of a response are very poor. Thus from these trials the time of implanting relative to when the rams are put out is of prime importance.

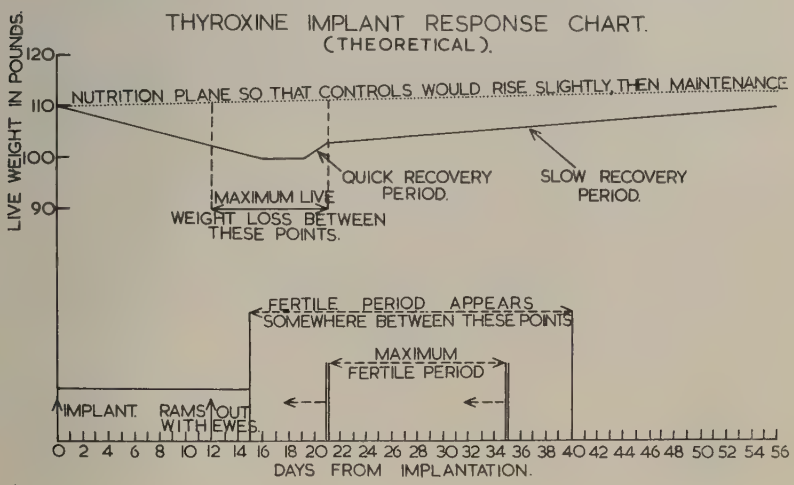
THYROXINE IMPLANT RESPONSE CHART.
(THEORETICAL).
LIVE WEIGHT IN POUNDS.
120
110
100
90
NUTRITION PLANE SO THAT CONTROLS WOULD RISE SLIGHTLY, THEN MAINTENANCE
QUICK RECOVERY PERIOD.
SLOW RECOVERY PERIOD.
MAXIMUM LIVE WEIGHT LOSS BETWEEN THESE POINTS.
FERTILE PERIOD APPEARS SOMEWHERE BETWEEN THESE POINTS
MAXIMUM FERTILE PERIOD
IMPLANT.
RAMS OUT WITH EWES.
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48 50 52 54 56
DAYS FROM IMPLANTATION.

Fig. 4.—Theoretical implant response chart.

The site of implantation also appears to play a part in determining the rate at which absorption of the implanted pellet takes place. The rate of absorption is of importance in determining the live-weight loss curve, which may not be fast enough or of suffiicent magnitude to bring about a fertility response if the absorption rate is too slow, but it may still be sufficient to give a satisfactory wool and lactation response. To some extent this theory of the critical nature of the fertility response may explain the results obtained by Coop and Clark (1958) who used the brisket as their implantation site during their first three years of

experimenting. In 1955 they obtained a wool-growth response but failed to demonstrate a significant fertility response. A similar result was obtained in 1956 by the same workers but in this instance the doubt about obtaining a fertility response was further increased by the rams not being put out until 23 days following implantation. By 1957 the data incorporated in the theoretical fertility chart (Fig. 4) was available and Coop and Clark changed the implanting site to the point behind the shoulder, putting the rams out 14 days later. Unfortunately on this occasion the type of implant had been varied slightly in the manufacturing process, which, whilst not affecting it seriously chemically, did affect it biologically by slowing down the rate of absorption of the thyroxine to such an extent that, as subsequent tests showed, the pellets were not able to bring about the usual loss of live weight even in housed sheep kept on a constant diet. As a result, in the 1957 trial, fertility responses were once again not significant. However it should be pointed out that over these trials the percentage of barren ewes tended to favour the control animals.

The dose level also appears to have a more critical effect on fertility than on the other forms of response. Table 5 shows a significant difference in favour of the 60 mg implant when compared with the 90 mg implant, although both treatments were superior to the controls. It should be remembered that this particular set of results refers to mature ewes only. With the mature ewe group there is no doubt that the higher the dose the greater the weight loss (Coop and Clark 1958). Because of the apparent close association between both the speed and magnitude of the weight loss, and fertility, obviously the live weight of the animal at the start is of importance in determining the fertility result obtained from a given dose. Mature ewes weighing up to 125 lb appear to give optimum fertility from a 60 mg dose, whereas when they were given 90 mg the positive response was reduced slightly and in cases of light weights may be a negative one.

With two-tooths, however, the dose level appears to be of even greater importance and far more critical. The results obtained by Ross and Lewis (1958) with their two-tooths, which were given a dose of 90 mg whilst not actually showing a significant reduction in the fertility of the treated group, do show a sufficiently reduced number of multiple births to indicate that these young sheep may not have been endocrinologically mature enough to take 90 mg of thyroxine. It may be argued that this is a rather liberal interpretation of Ross and Lewis' results, as they had already moved too close to the end of the "fertile period" for maximum results, by not putting the rams out with the ewes until 20 days after implantation, and this may also have been a contributing factor towards the poorer performance of the treated group. Table 6 presents figures that allow some comparison between the performance of mature and two-tooth ewes from the same stud flock when each group was given the large dose of 90 mg thyroxine and managed under similar conditions. Whilst once again in neither case is the difference statistically significant it may be inferred that the two-tooths have been more adversely affected than the mature sheep. Reduction of the two-tooth dose to 30 mg as shown in Table 7 appears to have at least halted the trend towards reduced fertility and suggests

that the two-tooth optimum absorption capacity may be somewhere about that level, when the fertility effect only is to be considered.

Speculation as to the mode of the response must be, for the present, rather indefinite. At the moment there does appear to be evidence suggesting that the contribution of the actual hormone itself may not be the operating factor, in that animals given thyroxine in the slow absorption form, (e.g. pellets of 1957-1959 vintage), failed to lose live weight and failed to respond reproductively, but did give a wool growth response, although of reduced magnitude. Thus it appears that a live-weight loss approximating to the theoretical one shown in Fig. 4 must be induced before there is any possibility of a fertility response. The amount, duration, and pattern of this loss, as defined by age and weight of the sheep, together with the thyroxine dose level and absorption rate, appear to be important factors in determining whether a fertility response will occur.

The possibility also exists that the increased metabolic rates and feed intake levels which Ferguson (1958) and Kirton *et al.* (1959) have shown take place in thyroxine-treated sheep may also be contributing in some way towards the increased reproductive and ovulation performances of these ewes. In such cases the increased appetite and food intake would appear to be the essential factors in stimulating a reproductive response and the thyroxine merely one means, amongst others, of achieving this end.

From the data obtained in these experiments it is thus impossible to offer any additional precise definition as to the physiological reactions capable of stimulating an increased reproductive performance in ewes and this continues to be a serious handicap in attempting to evaluate the use of thyroxine. However, it has been shown that the thyroid gland and its secretions play some part in sperm production in the male and that the administration of thyroxine may increase sperm production (Maqsood 1951), but the exact role of thyroxine in the production of the female ovum has not yet been so clearly defined.

Conventional "flushing" of ewes involving an increase in live weight results in increased ewe fertility: likewise ewes treated with thyroxine so that there is a period when they are increasing in live weight, if tupped, also are capable of showing increased fertility. Whether the common denominator of "increasing live weight" is the causal factor or merely evidence of it has not yet been decided. On the other hand it may be that the impact of excess thyroxine on an endocrine system already in the reproductive phase, results in a fertility effect divorced entirely from the other associated effects of live-weight loss, increased metabolic rates, and increased feed intake; and that one is dealing with a different response mechanism altogether from the conventional "flushing" ones.

However, the results of these experiments will not supply the answer to this question, but they do indicate that it is possible to affect significantly the fertility of breeding ewes either positively or negatively by the administation of thyroxine in the manner described. While the postive effect can be obtained it closely approximates that brought

about by conventional "flushing practice" in most respects, except that it is achieved "artificially" without the necessity of providing the special additional "flushing" feed normally required.

Acknowledgments

These experiments were conducted under a grant from the Nuffield Foundation. The supplies of thyroxine pellets were provided by Glaxo Laboratories (N.Z.) Ltd., and at Greenford (England); and the experiments were carried out with the co-operation of the stud breeders and farmers who made the sheep available for experimental purposes.

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PRODUCTIVITY OF PASTURE SPECIES ON HILL COUNTRY

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(*Received for publication, 14 March 1960*)

Summary

Twenty-seven pasture species were sown in plots on high-rainfall hill country. Annual and seasonal productions were measured by monthly herbage cuts over a period of three years. The results are discussed with reference to the usefulness of the species in hill pastures.

Introduction

The hill pastures of the North Island of New Zealand contain a large variety of species growing in association and all contributing in varying degrees to pasture production. At the Grasslands Division hill-pasture research station at Te Awa, by oversowing clovers and by mineral topdressing, carrying capacity of the area has been raised from $1\frac{1}{2}$ ewes plus cattle to 5 ewes plus cattle, over a period of eight years (Suckling 1959). This performance has been noteworthy in view of the fact that the improvement has been mainly in an increase of legumes and ryegrass, but the sward still remains typical hill-pasture containing varying proportions of so-called weed grasses, annual clovers, and weeds.

At the same time in some of the most fertile districts in the North Island, on sown pastures of ryegrass/white clover dominance, carrying capacity can reach 8–10 ewes per acre although the average is in the vicinity of 5 ewes. In view of this it was considered desirable to study the "poorer" pasture species in pure stands with adequate fertiliser to determine their relative seasonal and total productions in a hill country environment.

Experimental

Climate and Topography

The altitude of the site is approximately 1100 ft above sea level and slopes to the north. Rainfall over the past 9 years has averaged 43 in. with a monthly average between 2 and 4.5 in. The summers of 1954-5-6 were "droughty" with only light rainfall through the summer and autumn months (Fig. 1). During such seasons, seeds of annual clovers germinate with each successive light autumn shower then shrivel up with drying winds and sunshine. On the other hand, in wet summers, annual species have been observed to persist throughout the summer and into the autumn, to set and shed seed, which has then germinated alongside the still-surviving parent plants. The production potential of annual clovers can thus be markedly influenced by climatic conditions. However, useful though such annual species have been at Te Awa, it is possible to grow perennial grasses and clovers very satsifactorily on this area which was regarded locally as being climatically and topographically

difficult. Fig. 2 shows the mean monthly earth temperatures at 4 in. depth and can be correlated with species growth curves shown in Figs. 3, 4 and 5.

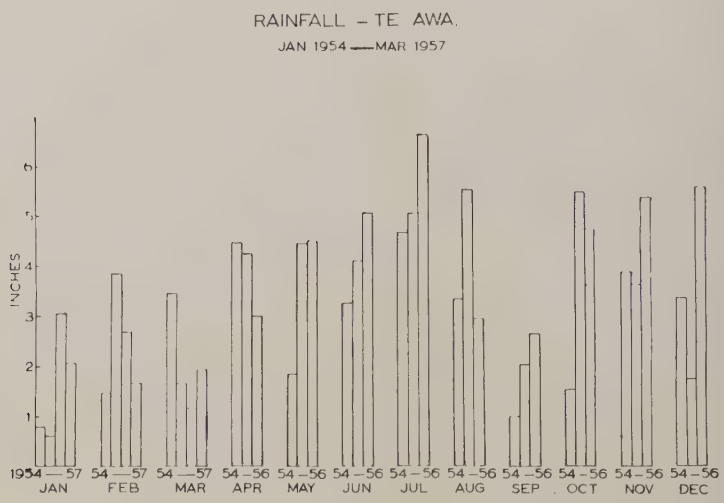

Fig. 1.—Rainfall at Te Awa for the period January 1954-March 1957. Recordings taken 9.30 a.m.

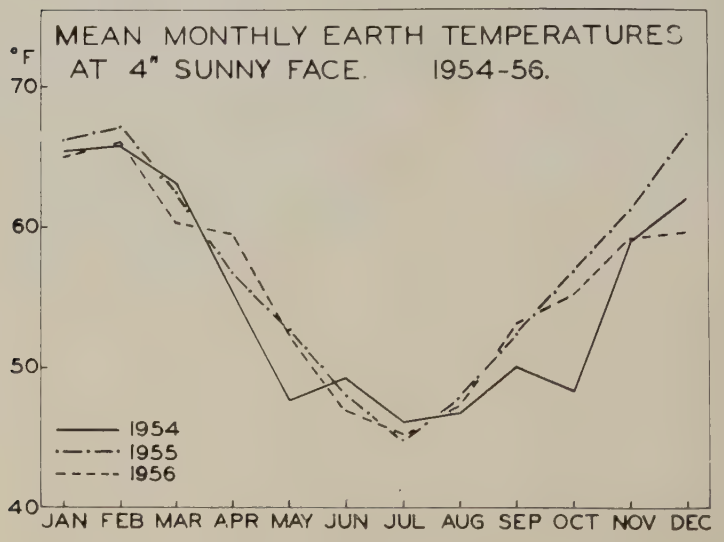

Fig. 2.—Mean monthly earth temperatures at 4 in. on a sunny face at Te Awa for the period 1954-56. Readings taken 9.30 a.m.

The Te Awa area and its soil type are representative of some 34,000 acres of moderately steep hill country. It is part of the extensive Wanganui peneplain and consists of Castlecliffian marine sands, laid down under shallow water adjacent to a coast-line, hence the soil is largely from coarse unconsolidated quartz sands. The soil profile is 5 in. dark greyish brown sandy loam, 9 in. pale brownish grey sandy loam mottled, on compact sands. The soil type is described by the N.Z. Soil Bureau (1954) as Raumai sandy loam (11H).

Layout and Procedure

Twenty-seven pasture species were sown separately in 2 ft x 3 ft plots in six randomised blocks. Each species was replicated six times to cover irregularities in soil and topography.

The species sown were:

Grasses

Italian ryegrass *Lolium multiflorum*; perennial ryegrass *L. perenne*; short-rotation ryegrass *L. perenne* × *multiflorum*; crested dogstail *Cynosurus cristatus;* cocksfoot *Dactylus glomerata;* danthonia *Danthonia pilosa;* Chewings fescue *Festuca rubra var. commutata;* browntop *agrostis tenuis*; annual meadow grass *Poa annua;* rough-stalked meadow grass *Poa trivialis;* Yorkshire fog *Holcus lanatus;* sweet vernal *Anthoxanthum odoratum.*

Clovers

White clover *Trifolium repens*; subterranean clover var. Mt. Barker, subterranean clover var. Tallarook, *T. subterraneum;* broad red clover, Montgomery red clover *T. pratense;* strawberry clover *T. fragiferum;* lotus major *Lotus uliginosus;* birdsfoot trefoil *Lotus corniculatus;* hairy birdsfoot trefoil *Lotus hispidus;* suckling clover *Trifolium dubium;* striated clover *T. striatum;* clustered clover *T. glomeratum.*

Weeds

Ribgrass *Plantago lanceolata;* catsear *Hypochaeris radicata;* hawkbit *Leontodon hispidus.*

In order to facilitate early weeding the seed was sown in 4 in. drills in March 1954. Seed rates were heavy in all cases to overcome germination difficulties with certain lines of seed, and the drills uniformly thinned to prevent overcrowding of the plants. As the trial was carried on for three years, it was necessary to resow the annual species each March.

Some difficulty was experienced in the first year with invasion of the plot area by grass grub (*Costelytra zealandica* (White)). However, applications of DDT soon overcame the problem.

All plots were uniformly topdressed with heavy rates of fertilisers to ensure that soil nutrients were not a limiting factor. Rates of fertiliser application were determined on the calculated removal of nutrients by a 14,000-lb d.m. pasture (McNeur 1953). Fertiliser dressings were applied every three months.

The herbage from all plots was cut monthly except for the first few months when establishment was relatively slow. At no time was the area subjected to stock grazing.

All herbage removed from the plots was weighed and samples retained for purity and dry-matter determinations. Seasonal aliquots were taken of the monthly dry-matter samples and total nitrogen determinations made on the crude-protein content of the herbage of the various species.

RESULTS

Because of the slow establishment during the first autumn and winter, it was not possible to record seasonal production for that period. For the purposes of this paper therefore, it has been decided to disregard the production data for the first year.

It will be seen from Table 1 that the total production figures are high when compared with recognised standards for pasture production. It must be borne in mind that in these trials:

(1) A heavy fertiliser programme including high nitrogen applications was followed.

TABLE 1. DRY MATTER PRODUCTION (lb/ac) AVERAGE FOR TWO YEARS

Species	Autumn	Winter	Spring	Summer	Total
1. Italian ryegrass	2,220	2,780	7,230	6,670	18,860
2. Perennial ryegrass	4,880	2,700	5,720	10,450	23,770
3. Short rot. ryegrass	3,070	3,000	6,330	7,790	20,180
4. Crested dogstail	1,560	1,120	2,310	1,510	6,500
5. Cocksfoot	4,740	1,580	5,360	7,970	19,650
6. Danthonia	1,350	1,490	3,180	4,130	10,150
7. Chewings fescue	3,350	1,920	3,270	4,630	13,160
8. Browntop	2,230	1,090	2,860	1,400	7,580
9. *Poa annua*	760	1,150	2,200	170	4,280
10. *Poa trivialis*	790	1,520	860	390	3,570
11. Yorkshire fog	1,800	2,190	5,350	4,760	14,140
12. Sweet vernal	1,400	1,600	3,680	2,050	8,730
SEs for Grasses	± 190	± 140	± 320	± 430	± 740
13. White clover	2,080	440	2,350	4,550	9,410
14. Mt. Barker sub.	1,470	500	6,640	1,210	9,820
15. Tallarook sub.	1,430	510	6,800	3,150	11,880
16. Broad red clover	3,100	520	4,960	9,490	18,070
17. Mont. red clover	3,270	730	5,550	14,060	23,600
18. Strawberry clover	700	670	1,220	2,000	4,590
19. *Lotus uliginosus*	1,410	640	2,520	5,820	10,390
20. *Lotus corniculatus*	2,080	60	2,890	7,710	12,740
21. Suckling clover	60	40	2,150	3,090	5,340
22. Striated clover	200	470	4,800	3,180	8,660
23. Clustered clover	105	600	2,860	2,690	6,250
24. *Lotus hispidus*	550	40	2,890	6,930	10,400
SEs for Legumes	± 150	± 110	± 280	± 390	± 640
25. Ribgrass	4,140	370	4,750	9,180	18,430
26. Catsear	1,590	160	2,490	7,830	12,080
27. Hawkbit	950	50	1,230	6,130	8,370
SEs for Weeds	± 170	± 90	± 200	± 460	± 930

(2) Small plots with cultivated pathways between plots over-emphasise production rates. Under these circumstances the outside edges of all plots showed increased growth over that grown in the centre of the plot, probably from extra moisture.

(3) There was a tendency for the plots to enlarge during periods of rapid growth and also for plants to overhang the pathways and, although regularly trimmed back to $3\frac{1}{2}$ sq ft plots, this factor could also have exaggerated production data.

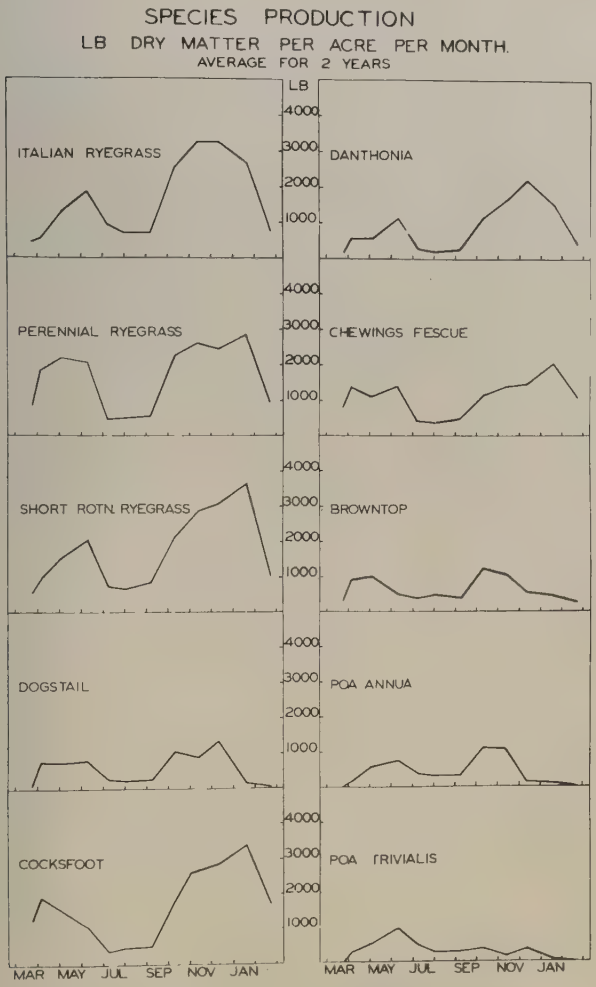

Fig. 3.—Dry-matter production of various species.

(4) Although production rates are high, comparisons between plots and species are probably valid, as all plots were subjected to the same treatment and were defoliated at the same time each month.

Table 1 shows seasonal and average productions of the various species, for the two-year period 1955-56 and 1956-57. Seasonal dry-matter percentages are shown in Table 2 for all species as are crude-protein percentages in Table 3.

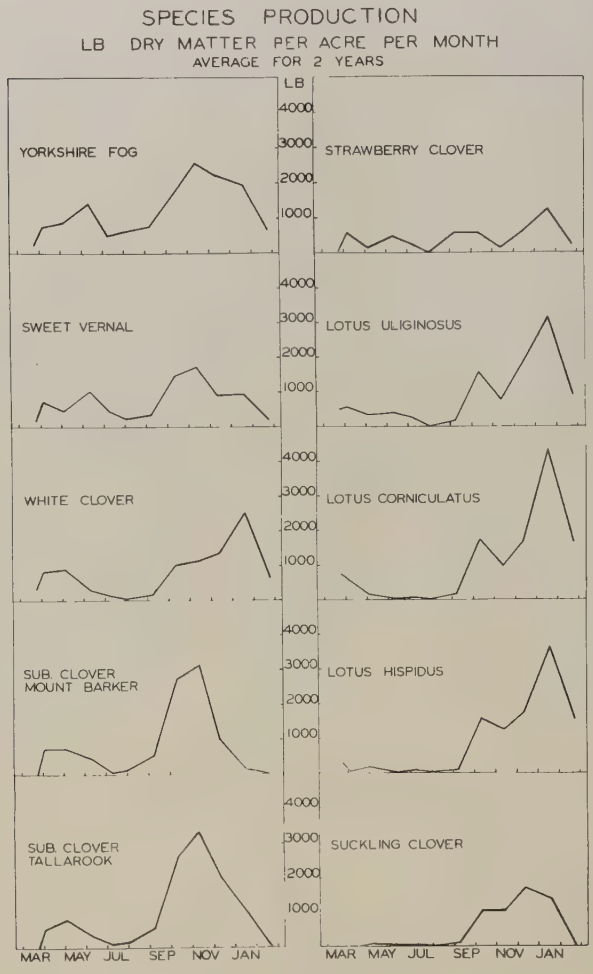

Fig. 4.—Dry-matter production of various species.

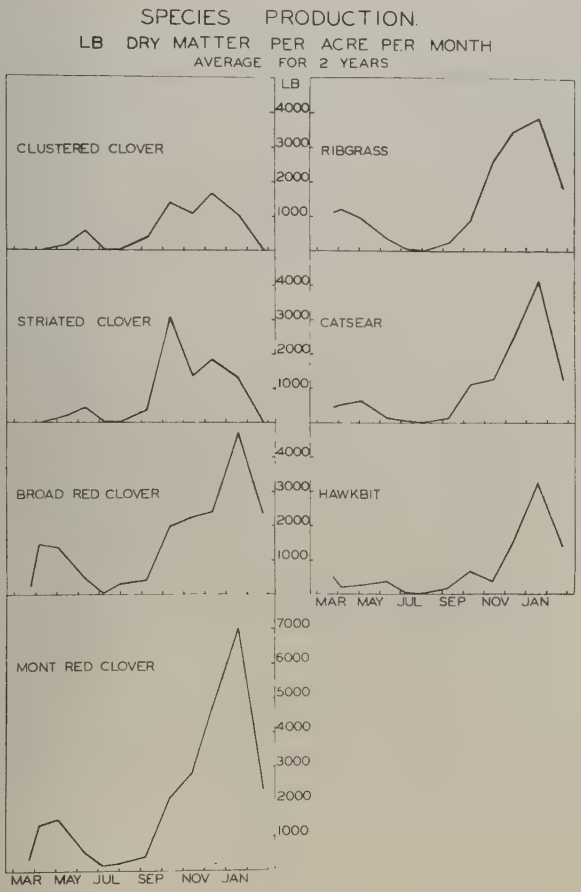

Fig. 5.—Dry-matter production of various species.

Figs. 3, 4 and 5 show graphically the average annual production of all 27 species. The curves are plotted to monthly cutting dates.

Percentage Dry Matter of Species

The average seasonal and annual dry-matter (d.m.) percentages of the herbage from all species were calculated, and are shown in Table 2. It can be seen that for the grasses the d.m. percentages are mostly highest in the summer, averaging 26.5% for all species. Winter d.m. percentages are higher than those for spring or autumn, i.e. 23.8% winter, 22.3% autumn, and 22.8% spring. The three species showing consistently higher d.m. content are danthonia with 29.2% average (31.2% summer), Chewings fescue 26.0% (29.3% summer), and browntop 26.2% (28.0% summer).

For the clovers the trend is different from that of the grasses, winter d.m. being the highest with 26.2% average for all species. Autumn, spring, and summer d.m. percentages are all fairly even, i.e., 21.5%, 21.0%, and 21.4%; striated clover has the highest d.m. content of the clovers with 25.2% average for the year.

TABLE 2. SEASONAL AVERAGE DRY MATTER % 1955-56–1956-57

Species	Autumn March-May	Winter June-Aug.	Spring Sept.-Nov.	Summer Dec.-Feb.	2 yr Average
Grasses					
Italian ryegrass	19.4	18.5	18.6	26.2	20.7
Perennial ryegrass	21.6	22.4	21.2	22.3	21.9
Short-rotation rye	19.5	20.4	19.4	25.8	21.3
Crested dogstail	24.2	25.1	21.5	29.5	25.1
Cocksfoot	21.6	23.0	22.1	25.3	23.0
Danthonia	29.4	29.6	27.7	30.1	29.2
Chewings fescue	23.6	27.0	24.3	29.2	26.0
Browntop	26.7	26.5	23.5	28.0	26.2
Poa annua	19.0	23.8	25.1	23.1	22.7
Poa trivialis	17.2	26.7	25.5	22.9	23.1
Yorkshire fog	22.9	18.7	19.6	26.9	22.0
Sweet vernal	22.2	23.9	25.0	28.3	24.8
Clovers					
White clover	22.5	26.5	20.0	23.4	23.1
Mt. Barker sub.	18.4	25.2	20.5	20.6	21.2
Tallarook sub.	21.2	32.0	19.9	21.1	23.5
Broad red clover	18.0	22.2	18.4	18.0	19.1
Mont. red clover	24.1	32.5	20.7	20.5	24.4
Strawberry clover	22.8	26.2	19.4	24.3	23.2
Lotus uliginosus	21.4	26.5	20.3	20.6	22.2
Lotus corniculatus	20.5	27.2	18.8	20.3	21.7
Suckling clover	21.0	26.7	22.9	24.9	23.9
Striated clover	27.6	26.5	26.3	20.3	25.2
Clustered clover	20.0	21.0	22.2	20.2	20.8
Lotus hispidus	20.6	21.9	23.0	22.5	22.0
Weeds					
Ribgrass	17.2	29.0	17.3	19.4	20.7
Catsear	15.7	27.0	16.3	19.0	19.6
Hawkbit	18.4	23.0	20.4	18.6	20.1

The d.m. content of weeds is highest in the winter with 26.5%, 17.1% for the autumn, 18% for spring and 19% for summer.

Protein Content

Chemical analyses to determine the protein content of each species were made for spring, summer, autumn, and winter, and are shown in Table 3.

From the table it will be seen that, for the grass species, crude protein (c.p.) percentages were highest during winter at 23.3%, with those for autumn slightly lower at 22.4%. The average for spring was 17.4% and summer 15.4%. The highest percentages during winter were 26.3% for cocksfoot and 25.8% for browntop. Italian ryegrass contained the lowest percentage at 14.2% in summer.

Legumes differed slightly from the grasses in order of seasonal c.p. percentage, the highest figures being recorded in winter 22.1%, spring 21.1%, autumn 20.5%, and summer 19.4%. The average c.p. percentage of the legumes was slightly lower in autumn and winter than for the grasses but higher during spring and summer. The highest figure was recorded for white clover 26.2% and *Lotus corniculatus* 25.1% in winter. The lowest, 15.3%, was recorded in autumn for *Lotus hispidus*.

Crude protein percentages were at a slightly lower level for the weed species than for grasses or legumes for spring, summer, and autumn, but were higher than the average for grasses during summer, and followed the same seasonal trend. Of the three species examined catsear had the highest seasonal figure, 24.2% recorded during winter. The lowest was for ribgrass, 15.2% in summer and autumn.

TABLE 3. SEASONAL AVERAGE PROTEIN CONTENT OF SPECIES FOR THE YEARS MARCH 1955-56 AND MARCH 1956-57

Species	Autumn	Winter	Spring	Summer	2 yr Av. C.P. %
Grasses					
Italian ryegrass	23.4	25.1	16.8	14.2	19.9
Perennial ryegrass	22.5	22.0	15.3	15.4	18.8
Short-rotation rye	24.9	21.9	18.3	15.5	17.6
Crested dogstail	20.5	21.1	18.1	15.1	18.7
Cocksfoot	22.2	26.3	18.5	15.9	20.7
Danthonia	21.9	24.7	17.8	14.3	19.7
Chewings fescue	22.8	24.1	19.0	16.8	20.7
Browntop	22.7	25.8	17.0	16.5	20.5
Poa annua	22.1	22.6	15.3	15.3	18.8
Poa trivialis	23.8	19.0	16.9	15.4	18.8
Yorkshire fog	21.5	22.7	18.1	15.7	19.5
Sweet vernal	21.2	24.2	16.6	15.1	19.3
Av. for grasses	22.4	23.3	17.4	15.4	
Clovers					
White clover	22.9	26.2	21.7	21.0	23.0
Mt. Barker sub.	23.9	24.1	19.8	19.6	21.9
Tallarook sub.	22.5	23.0	20.7	16.5	20.7
Broad red clover	22.7	22.9	21.1	20.1	21.8
Mont. red clover	18.1	21.9	23.2	21.1	21.1
Strawberry clover	20.8	20.8	19.9	19.5	20.3
Lotus uliginosus	21.7	20.9	22.4	20.6	21.4
Lotus corniculatus	23.6	25.1	21.8	20.1	22.7
Suckling clover	16.3	18.5	20.4	18.2	18.4
Striated clover	19.8	19.8	21.5	20.0	20.3
Clustered clover	18.5	20.1	19.5	16.0	18.5
Lotus hispidus	15.3	20.2	21.4	19.9	19.7
Average for legumes	20.5	22.1	21.1	19.4	
Weeds					
Ribgrass	15.2	19.5	15.7	15.2	16.4
Catsear	23.7	24.2	17.4	16.4	20.4
Hawkbit	16.0	20.1	16.2	15.6	17.0
Av. for weeds	18.3	21.3	17.0	15.7	

Discussion

For the purpose of this discussion, various species can be grouped:

Grasses

In Figs. 3 and 4, and from Table 1, it can be seen that most of the perennial grasses under consideration had a relatively low rate of production during the autumn. Those species showing a higher percentage of their total production during this period were cocksfoot with 24%, crested dogstail 24%, Chewings fescue 25%, and browntop 29%. Perennial ryegrass produced 21% of its total production in autumn; however, comparing these species with perennial ryegrass on a relative basis taking ryegrass as 100, the figure for cocksfoot was 97, for dogstail 32, for Chewings fescue 68 and for browntop 46. It can be seen that perennial ryegrass produced more than the other grass species during the autumn. Cocksfoot, however, gave the highest production during the month of February.

The outstanding winter producing species were Italian ryegrass (103), short-rotation ryegrass (111), perennial ryegrass (100), and Yorkshire fog (81). *Poa trivialis* (56) produced 43% of its total production at this time. Although none of the other grasses show complete winter dormancy, production rates were generally low.

In the spring months all the grasses made rapid growth, the highest spring production being made by Italian ryegrass (127), short-rotation ryegrass (110), perennial ryegrass (100), with cocksfoot (94) and Yorkshire fog (93) following closely perennial ryegrass.

Several of the grasses reached the peak of their production in summer, i.e., December and January, while Italian ryegrass, Yorkshire fog, sweet vernal, browntop, and *Poa annua* made maximum growth in October and November.

Poa trivialis differed from the other grass species in its general growth curve under plot conditions in a pure stand. Observations regarding this species, when growing in pastures in association with other species, indicate that wet, shady conditions are most suitable for its maximum growth. Levy (1925) lists *Poa trivialis* as a species suited to wet and fertile soils, and states that it will not thrive on moderately dry soils. He also places *Poa trivialis* high on the list of pasture plants capable of tolerating shady conditions. It would appear that the growth curve obtained in the present trials is not a true picture of its general production. Conditions on the plot area, which sloped to the north, were moderately dry and sunny.

Clovers

Figs. 4 and 5 show the seasonal production trends for the clover species. In the autumn, production from clover species depends largely on the continuity of early autumn rainfall, this being particularly so with the annual species. If autumn rains commence late in the season, there is little growth before cold winter conditions set in. Striated, clustered, and suckling clovers and *Lotus hispidus* show very

little growth until the spring. Subterranean clover on the other hand makes about 30% of the production of perennial ryegrass in the winter period.

Of the perennial clovers, cowgrass and Montgomery red clover were the highest-producing species in autumn, with about 65% of the production of perennial ryegrass. White clover for this period produced 43%.

The graphs show that all clover species were influenced greatly by cold conditions and, in all the clovers under test, very little growth occurred in July when earth temperatures on the site dropped to 45° at 4 in. depth. Again, comparing the clovers in relation to ryegrass production for this period, the relative figures of note are Montgomery red clover 27%, strawberry clover 25%, lotus major 24%, and clustered clover 22%.

Spring is the most prolific season for the growth of most of the clovers. The annual clovers and white clover generally reach peak growth in October and November while the red clovers and *Lotus* species, although later, contribute over a longer period into the summer. Species comparing most favourably with perennial ryegrass production in spring are Mt. Barker subterranean clover 116%, Tallarook subterranean clover 119%, Montgomery red clover 97%, cowgrass 87% and striated clover 84% of the production of perennial ryegrass.

The outstanding summer clovers are Montgomery red clover, 134% of perennial ryegrass production, cowgrass 91%, and *Lotus corniculatus* 74%.

Weed Species

Of the three weed species studied, ribgrass has the highest production. Compared with perennial ryegrass, ribgrass produced 78% for the two-year period, catsear 51%, and hawkbit 35%. Most of this growth was made during the spring months, reaching a peak in January. The growth curves are similar for all three species.

General

Some interesting points arise out of this trial which may be summarised.

(1) The two subterranean clover varieties, Mt. Barker and Tallarook, which have been shown to be most suited to New Zealand conditions (Levy and Gorman 1937) are usually sown together. This is because a greater spread of production is achieved with Mt. Barker flowering in the middle of spring and Tallarook flowering later. Fig. 2 shows that at Te Awa their production curves are very similar except that Tallarook continues growth longer into the summer.

(2) In the autumn of 1957, *Poa annua* and *Poa trivialis* made no growth. Similarly, the annual clover species, Mt. Barker and Tallarook subterranean clover, suckling, striated, and clustered clovers, and *Lotus hispidus*, did not grow during the period because of dry conditions. In the previous autumn (1956), with

some early rainfall, growth was recorded. Seasonal variations in yield are again shown in the winter production of clover species. In 1955 some herbage was produced, whereas no harvestable growth was made in the winter of 1956 by any of the clover species.

It is apparent from the data that great variations in pasture and species production can occur with varying climatic conditions. Over the three years of the trial great differences were recorded in seasonal and total production from all species. These results therefore give only an approximation of the relative growth of the various grass and clover species, and the time their contributions to annual pasture productions are made.

Usefulness of Species in Hill Pastures

The various species shown in the table can be listed in order of annual productivity when compared with perennial ryegrass (= 100).

Grasses. Perennial ryegrass (100); short-rotation ryegrass 85; cocksfoot 83; Italian ryegrass 80; Yorkshire fog 59; Chewings fescue 55; *Danthonia* spp. 43; sweet vernal 37; browntop 32; crested dogstail 27; *Poa annua* 18; *Poa trivialis* 15.

Legumes. Montgomery red clover 99; broad red clover 76; *Lotus corniculatus* 54; Tallarook sub. clover 50; *Lotus uliginosus* 44; *Lotus hispidus* 44; Mt. Barker sub. clover 41; white clover 40; striated clover 36; clustered clover 26; suckling clover 22; strawberry clover 19.

Weeds. Ribgrass 78; catsear 51; hawkbit 35.

Both point-analysis and herbage dissection records from the Te Awa hill country pastures show that there is only a relatively small proportion of perennial ryegrass in the overall sward. Ryegrass is usually dominant on the high fertility areas such as hilltop stock camps, stock tracks, and valley bottoms. As these areas represent only a small proportion of the total area, it is apparent that the overall production from this species is low.

The steeper hillsides are generally lower in fertility, and support the growth of the other grasses, mainly browntop on the moister areas and danthonia on the dry faces, with varying proportions of crested dogstail, Chewings fescue, *Poa pratensis*, sweet vernal, Yorkshire fog, hairgrass, and flat weeds. In most North Island hill pastures weed species occupy the greater part of the total area. Levy (1924) points out that the more uneven the hill country and the more variable the form of management, the greater the need for a big range of adaptability in the mixtures of grasses and clovers that are sown. He also expresses the opinion that it is largely the lack of turf-forming grasses that has led to so much deterioration of hill country to weeds and fern. In the meantime it is obvious from the present data shown that most of the species dealt with in this paper are of value on hill country, particularly where the herbage produced is fully utilised by stock. The lower-producing grasses all seed early in the spring and if not heavily grazed and fully utilised rapidly become unpalatable to stock. Under close grazing the hard and usually unpalatable danthonia is readily consumed.

It is of interest to note the relatively high production of some of the weed species, particularly ribgrass. Of the species tested, ribgrass produced 78% of perennial ryegrass production and was superior to most of the clovers excepting the two red-clover varieties. Experimental work at the Welsh Plant Breeding Station (Stapledon 1940; Thomas 1941) has shown that, on the poorest lands of the Cahn Hill Improvement scheme lambs have been fattened on ribgrass almost as well as on rape.

ACKNOWLEDGMENTS

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PLANT GROWTH IN EXPANDED PERLITE

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Summary

The chemical and physical properties of expanded perlite as a growth medium are described.

The growth of cress in perlite receiving additions of inorganic fertilisers is described and assessed. Only slightly less growth was made in perlite fortified with plant nutrients than in a good potting soil.

The medium is simple to handle and is suitable for the growth of plants in less than optimal conditions.

Introduction

Perlite† is similar to pumice in that it is formed from an acid volcanic rock, but it is lighter through artificial heat treatment (Thompson and Read 1954; Dunn and Billinghurst 1954). It has been recommended as a soil amendment and there was therefore interest in its properties. In addition, there was need to supply a simple growth medium for the growth of cress in the Antarctic (Morrison 1956), and it was decided to test perlite for this purpose.

Properties

Chemical

Base exchange capacity		1.5 me.%
Total exchangeable bases		1.1 me.%
% Base saturation		73%
Exchangeable cations:	Ca	6.0 me.%
	Mg	0
	K	0.15 me.%
	Na	1.1 me.%
Soluble in 1% acetic acid		
	P_2O_5	0.0015%

The very low exchange capacity of this material, combined with its very low content of available phosphorus, emphasises that perlite has very little nutriment to contribute as a growth medium. Any benefits as a soil amendment or as a growth medium should thus be sought in its physical properties.

Physical

Fig. 1 sets out the grading curves for a "fine" and a "coarse" perlite, compared with well-graded pumice subsoil passing a 2 mm sieve. The data show that perlites are coarser in texture than the pumice in these samples.

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† AGYO supplied by Giles and Elliot Ltd., Wellington.

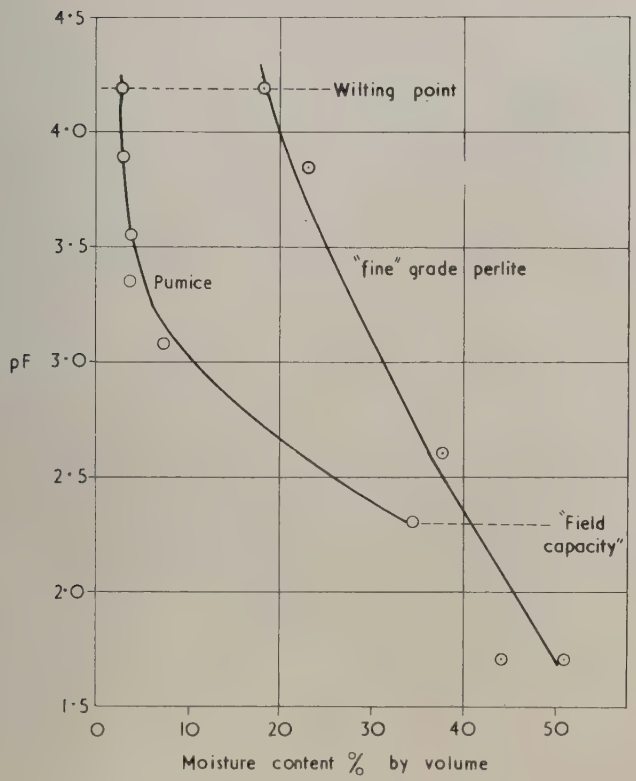

Fig. 1.—Grading curves for expanded perlite and a comparable pumice sample.

TABLE 1. PARTICLE DENSITIES OF SIZE FRACTIONS OF PERLITE

Sieve Size Range	Particle Density g/ml
Larger than 2 mm. (10*)	0.820
10– 20*	1.052
20– 40	0.829
40– 60	1.234
60–100	1.536
100–200	1.841
Finer than 200	n.d.

* A.S.T.M. Sieve Sizes.

In Table 1 are compared the particle densities of the different-sized fractions of perlite. It can be seen broadly that as the fraction becomes smaller its particle density increases. This is a consequence of the porous nature of the perlite, the larger particles containing relatively more blocked pores. The average particle specific gravity of the "fine" grade is 1.15, compared with 2.35 for the pumice.

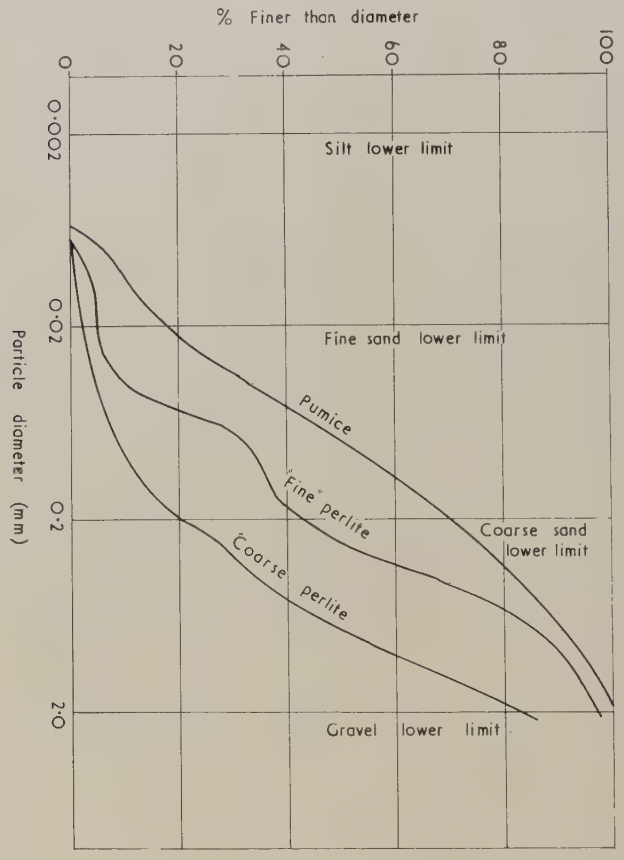

Fig. 2—Approximate pF—moisture content curves.

Fig. 2 gives the approximate pF/moisture curves for the "fine" grade perlite and a pumice soil for comparison. It will be noted that at a given pF perlite, although it is of coarser grading than the pumice, has a considerably higher moisture content than the pumice over the available water range. The comparatively high moisture retention of the perlite cannot be attributed to "inter-particle porosity" alone, and it is probable that much of it is due to open pores in the particles. Open particle pores can be observed microscopically on the unsectioned smaller

perlite particles and the existence of still smaller pores can be inferred from the relatively high moisture contents at the higher pFs compared with those for pumice. At the low tension end the curves of pF against moisture content by volume for pumice and perlite tend to converge. In support of this result it may be mentioned that a ground sample of pumice (particles passing the 20-mesh sieve) was found to retain 47.5% moisture by volume at pF 1.70.

Packard (1957) has shown that for pumice soils the moisture content at pF 2.30 is approximately the same as at field capacity. If the difference in moisture content (by volume) between pF 4.19 (wilting point) and pF 2.30 (field capacity) is regarded as "available moisture", reference to Fig. 2 shows that this value is greater for pumice than for perlite.

The aeration in perlite is considerable, e.g. at an apparent density of 0.134 the total porosity is 88.3% of which 37.4% is "large pores", i.e., drained at a tension equal to or less than 50 cm of water. It is to be noted that there is some tendency towards tighter packing as the perlite becomes drained, but it can be calculated from the figures given that at pF 2.60 there is still approximately 50% of water-free air space. Aeration at pF 2.30 for the pumice is also considerable, there being 29.4% of water-free air space, for a total porosity of 63.8%.

Although the available moisture is less for perlite than for pumice, this is of no great moment in glasshouse culture where the water supply can be kept up. What is of consequence is the water-free air space at low tensions—a factor that makes for healthy growth. Thus, perlite was considered to be well worth a trial in pot experiments.

Pot Experiments

Growth of cress in potting soil was compared with that in expanded perlite to which nutrients were added either as a dry powder spread over the surface and watered in (Douglas 1955) or as a standard nutrient solution (Hewitt 1952). Plants were grown in glass pots of 76 mm diameter to which all drainage was periodically returned. Plants were harvested after 3–4 weeks growth in a glasshouse by cutting off, drying, and weighing the shoots.

Results

Results presented in Table 1 are a summary of 7 separate experiments. Preliminary experiments demonstrated that perlite could not sustain growth of cress without added fertilisers, but that with suitable nutrient additions it provided a good growth medium. Both the nutrient solution and the dry powder (Bengal mixture, Table 3) when added at 7–10 day intervals produced similar growth to that in a potting soil. Any unbalance in the major nutrients of the dry mixture decreased growth although the omission of trace elements did not. This is not surprising since the commercial superphosphate used would supply some minor elements for a period. A typical spectographic analysis of superphosphate is as follows, in p.p.m.

Fe 750, Zn 100, Mn 200, Co 10, Cu 10, Mo 0.5 (Mr N. Wells, pers. comm.).

Expanded perlite has been used also in a practical method of raising garden seedlings (Morrison 1956).

TABLE 2. Dry Weight of Shoots of Cress Grown in Various Media

Medium	Dry Wt. (g/pot)	Total Replicates
Potting soil	1.4	7
Perlite		
Nutrient solution (Hewitt)	1.4	5
Standard Bengal Mixture (Table 3)	1.1	13
With double $NaNO_3$	1.0	7
With quadruple $NaNO_3$	1.0	3
With $(NH_4)_2SO_4$ replacing $NaNO_3$	0.3	3
With quadruple superphosphate	0.9	1
Without minor elements	1.1	5

TABLE 3. Standard Bengal Mixture*
(Relative proportions by weight)

Added at the rate of 0.31 g per 70 mm diam. pot.

Superphosphate	3.25	$MgSO_4.7H_2O$	2.0
$CaSO_4.2H_2O$	1.5	$NaNO_3$	7
K_2SO_4	2.5	Trace element mixture†	0.003

† Trace element mixture

$ZnSO_4.7H_2O$	1.5	$CuSO_4.5H_2O$	1.5
$MnSO_4.4H_2O$	4.5	$FeSO_4$	5.0
H_3BO_3	3.5	$(NH_4)_6Mo_7O_{24}4H_2O$	0.12

* Approximates to formula 10, p. 64 Douglas, Sholto J. (1955).

Conclusion

The work shows that despite its low nutrient content, perlite can be a very useful medium for plant growth. It has a good balance between water-holding power and aeration, it provides a good root run, and any deficiency in plant foods needed for short-term experiments can easily be made good with balanced fertilisers. It does not require much specialised attention so the medium is a safe one to use in semi-skilled hands.

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THE EFFECT OF CONDITION AT FARROWING UPON THE SUBSEQUENT MILK YIELD AND THE EFFICIENCY OF PRODUCTION

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(*Received for publication, 8 April 1960*)

Summary

The yield and composition of the milk, and the energetic efficiency of production of two groups of sows, one of which was in high condition at farrowing and the other in low condition, are reported. Both groups were fed on a low ration during lactation.

The sows in low condition lost less weight and produced slightly less milk and milk energy than those in high condition, the mean yields per sow being 546 and 579 pounds respectively for the last seven weeks of lactation.

Several methods have been evolved to estimate the energetic efficiency of production over gestation, lactation, and the whole reproductive cycle.

The effect of various feeding regimes at different stages of the reproductive cycle upon the energetic efficiency of the sow are discussed.

Introduction

Data obtained from a previous study carried out at this station (Smith 1959b) in which sows in high condition at farrowing were subjected to three levels of nutrition during lactation demonstrated the ability of the sow to offset the effect of low rations upon milk energy production by drawing upon body reserves.

It was decided, therefore, to investigate the effect of condition at farrowing upon subsequent milk energy yield, and to determine the extent to which body reserves must be depleted before yields were affected. At the same time the opportunity was taken to study the energetic efficiency of the whole reproductive cycle.

Experimental Material and Methods

Two groups of sows, one in high and the other in low condition at farrowing, were required for the experiment. Both these terms are obviously relative.

As a preliminary exercise the weight gains of some 100 well fed sows were examined over three successive gestations and lactations. It was found that sows at this station had been mated for the first time at a weight of 230 lb and had gained 130 lb during their first gestation, weighing 360 lb at farrowing. During their first lactation they lost 40 lb. During their second gestation they gained 130 lb, farrowing down at an average weight of 450 lb. During the second lactation the mean weight loss was 70 lb. In the course of the third gestation the average gain

was 110 lb, farrowing weight 490 lb, and the weight loss during lactation 70 lb. In each case the weight lost during lactation included the immediate post-farrowing losses. All figures quoted are averages.

In consequence of this general picture, it was decided to feed first- and second-litter sows of the high-condition group so as to gain 130 lb, and third-litter sows to gain 110 lb during gestation. Sows gaining weights of this order were considered to be in ideal farrowing condition, and had in fact, performed well in prevoius experiments. The sows comprising the group in low condition at farrowing were fed so as to gain 80 lb in the first gestation (while still growing), 60 lb in a second gestation when growth requirements were less, and 40 lb in a third or fourth gestation, at which stage mature size has been reached.

Eighteen Berkshire sows, farrowing within one month, were available and these were allotted in pairs, one to each group, at the time of mating.

The two groups were stied together, fed individually, and run as a group at pasture. The sows were weighed weekly and the rations adjusted after each weighing so as to achieve the prescribed gains prior to farrowing.

After consideration of the weight gains during gestation, five animals were selected from each group for the milk production trials. During gestation the sows were allowed approximately eight hours grazing per day on ryegrass/white clover pasture, and in addition each sow received sufficient separated milk to achieve her prescribed weight gain. During lactation the ration fed consisted of 40% separated milk and 60% concentrate (1 part 60% protein meat meal to 3 parts barley meal). One gallon of milk and one pound of the above concentrate mixture were regarded as equivalent to one feed unit. The rate of feeding was 3 units per sow, plus $\frac{1}{2}$ unit per piglet suckled.

The lactating sows were allowed access to pasture for one hour daily except in very wet weather.

The litters were offered supplementary feed to appetite from the age of three weeks. The feed consisted of the same concentrate mixture as for the sows, and separated milk, fed in separate troughs. Records of creep consumption were kept on a weekly basis.

Milk-yield Measurements

Milk-yield measurements were conducted once every 7 days and covered a period of 12 hours. The methods used have already been described in a previous paper (Smith 1959a).

Calculation of Energy Values

The methods used to calculate the energy values of sow and litter feedstuffs and the energy equivalent of changes in sow weight have already been described in previous publications (Smith 1959a, b).

The gross energy content of the litter at birth, one week, and 8 weeks of age, was calculated from data published by Berge and Indrebo (1954). A pig at birth was credited with 420 kilocalories per pound

liveweight; at one week of age, 753 kilocalories per pound; and at 8 weeks, 1055 kilocalories per pound.

Calculation of Energetic Efficiency of the Lactational Period

Four methods have been used to estimate the energetic efficiency of the sow and the litter over the seven weeks of recorded lactation.

The first method provides an estimate of the gross efficiency of milk production using the formula of Brody (1954) as described in a previous paper (Smith 1959a), viz:

Gross efficiency of milk production =

$$\frac{\text{Gross energy of milk produced (kcal)}}{\text{(t.d.n. intake of sow) } 1814 \pm WC^E} \quad . \quad . \quad . \quad . \quad . \quad . \quad 1$$

where WC^E is the energy equivalent of sow weight changes during the seven weeks over which milk yield was measured.

The second method provides estimates of the gross efficiency of litter production using the estimated increase in litter tissue energy from 1 to 8 weeks as the measure of production. The three expressions used were:

The gross efficiency of the last seven weeks of lactation =

$$\frac{(w^8 \times 1055) - (w^1 \times 753) \text{ kcal.}}{(Ic + Il^1)\ 1814 \pm WC^E} \quad . \quad . \quad . \quad . \quad . \quad . \quad 2$$

where w^1 and w^8 are the live weights of the litter at the end of the 1st and 8th weeks respectively, Ic is the t.d.n. intake of the litter from the creep, Il^1 is the t.d.n. intake of the sow over the last 7 weeks of lactation, and WC^E is the energy equivalent of weight changes over the same period.

The gross efficiency of energy conversion by the litter =

$$\frac{(W^8 \times 1055) - (W^1 \times 753) \text{ kcal.}}{S + (Ic \times 1814)} \quad . \quad . \quad . \quad . \quad . \quad . \quad 3$$

where S is the metabolisable energy content of the sow's milk available to the litter.

The final expression was devised to estimate the efficiency with which sow feed alone was converted to litter energy, after the energy intake and weight gains of the litter from creep feeding were excluded.

The gross efficiency of sow feed energy conversion =

$$\frac{\left[\left(W^8 - \frac{Ic \times 1814}{E} \right) 1055 \right] - W^1 \times 753 \text{ kcal.}}{Il^1 \times 1814 \pm WC^E} \quad . \quad 4$$

where E is the kilocalorie intake of sow's milk and creep feed energy per lb of litter gain for the period over which creep was fed.

The Energetic Efficiency of the Reproductive Cycle

Previous studies in this series, and the formulae developed above, have been exclusively concerned with the lactational period of the sow.

The two processes which comprise the reproductive cycle, pregnancy and lactation, are separate and sequential in the sow in contrast with the overlapping which normally occurs in cattle, and may therefore, be studied separately. It is suggested, however, that no study of sow nutrition is complete unless it deals with the whole process of reproduction. The importance of including the energy intake of the sow during gestation as well as that for lactation in efficiency calculations is illustrated by the data from the present experiment where 60% to 68% of the total feed energy consumption for the reproductive cycle occurred between mating and farrowing.

An attempt has therefore been made in this paper to develop and apply methods of evaluating the energetic efficiency of sows during gestation, lactation (8 weeks rather than 7) and for the whole reproductive cycle.

For purposes of the calculations, the period between mating and the weaning of the consequent litter has been regarded as a reproductive cycle. This definition does not include the interval between weaning and re-mating. This period has been ignored because of its variable length. It was found more convenient to work over definite periods such as 114 days for gestation and 56 days for lactation; a full cycle of 170 days.

Two methods have been used to provide estimates of energetic efficiency. The first, which is designated method A, uses the pattern described earlier in calculating the gross efficiency of the lactational period. This has been modified to provide a formula for the calculation of the energetic efficiency of gestation.

$$\frac{W^{o} \times 420 \text{ kcal.}}{Ig \times 1814 \pm W^{CEg}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 5$$

where Ig is the t.d.n. intake of the sow during gestation; W^{o} the weight of the litter at birth, and W^{CEg} the energy equivalent of sow weight changes during gestation.

In the present experiment the feed energy intake of the sows during gestation, "Ig" was a combination of the food provided in the form of separated milk and the feed energy intake from pasture.

Pasture consumption was not measured, but an attempt has been made to estimate the energy intake from this source.

The method used was as follows:—

(a) The formula of Brody *et al.* (1934), namely basal metabolism (in kcal.) = 70.5 M 0.734 when M is the weight of the sow in kilogrammes, was used, and the suggestion of these authors that maintenance requirements would be met by providing an intake equal to twice basal metabolism, was accepted.

(b) The mean weight of each sow over gestation was taken as the basic weight for the calculation of her maintenance requirements.

(c) The weight increment between mating and immediately after farrowing has been taken as the true weight gain during gestation, and the energy requirement in kcal calculated by multiplying this gain in pounds by 4925.

(d) The energy content of the litter at birth ($W^{o} \times 420$) was assumed to be 70% of the metabolisable energy used for its growth (Armsby and Moulton 1925).

The daily intake of metabolisable energy from pasture as calculated for each sow is shown in Table 1.

TABLE 1. The Calculated Maintenance Energy Requirements and the Estimated Energy Derived from Pasture for Individual Sows (Energy values in therms)*

Sow No.	Observed Feed Energy Intake	Energy Used for:		Left for Daily Maintenance	Calculated Daily Maintenance Required	Energy Derived from Pasture Daily
		Weight Gain	Litter Growth			
High						
127	680	542	9.0	1.1	4.7	3.6
120	740	369	17.0	3.1	6.7	3.6
122	835	389	16.0	3.8	5.9	2.1
106	833	305	17.0	4.5	7.1	2.6
102	598	296	19.0	2.5	6.5	4.0
Low						
119	416	148	16.0	2.2	5.5	3.3
121	436	128	16.0	2.6	6.0	3.4
117	443	− 17	18.0	3.9	6.5	2.6
107	315	44	16.0	2.2	6.7	4.5
126	420	246	11.0	1.4	4.5	3.1

* 1 therm = 1000 kilocalories.

Following the same pattern as for formula 5, the gross efficiency of the lactational period (8 weeks) may be calculated from the expression:

$$\frac{(W^{8} \times 1055) - (W^{o} \times 420) \text{ kcal}}{(Il + Ic)\ 1814 \pm W^{CEl}} \quad \ldots\ldots 6$$

when W^{CEl} is the energy equivalent of sow weight changes during lactation. Similarly the gross efficiency of the reproductive cycle may be calculated from the expression:

$$\frac{W^{8} \times 1055 \text{ kcal}}{(Ig + Il + Ic)\ 1814 \pm W^{CER}} \quad \ldots\ldots 7$$

where W^{CER} is the energy equivalent of sow weight differences between mating and weaning.

When expressed in percentages the values obtained from the application of the above formulae are estimates of the energy recovery in the form of litter tissue per 100 units of that part of the energy intake of the sow and litter which was used to maintain the sow and litter and

provide for litter growth. Thus, during gestation and lactation the energy required to produce weight gains (4925 kcal per lb) is subtracted from the feed intake since this part of the intake was not used directly either to maintain the sow or to support litter growth. On the other hand when sows lose weight during lactation it has been assumed that the energy derived from body reserves (3312 kcal per lb) has been used to support milk production. The energy equivalent of the weight loss has, therefore, been added to the observed feed energy intake in the denominator of the appropriate formula.

Expressions 6 and 7 may be modified in a similar fashion to that shown in No. 4, to exclude the creep energy intake and the litter gains attributable to this source of feed.

The essential features of method A are (1) the energy content of the litter at birth or at weaning is regarded as the sole product of the phase of the reproductive cycle under consideration and (2) when calculating energetic efficiency, the litter energy is expressed as a percentage of the "energy intake equivalent" of the sow and litter.

Method A, therefore, provides an estimate of the efficiency with which energy from all sources is used for litter production. In fact however there are two end products to gestation, lactation, and the whole reproductive cycle: the litter and the sow.

At the commencement of a reproductive cycle the body tissues of the sow contain a certain amount of energy. During gestation a litter is nurtured and grows and the sow usually gains weight, partly by the normal process of growth and partly by fat deposition in the case of younger animals, and mainly by the deposition of fat stores in the case of older animals. At the end of gestation the total energy recovery consists of the energy content of the litter plus the increase in the energy content of the tissues of the sow between mating and parturition.

Similarly, the end products of lactation consist of the increase in the energy content of the litter between birth and weaning and the difference in the energy content of the sow at the beginning and end of the same period, while the energy outcome of the whole cycle is the energy content of the weaned litter plus the difference in the energy content of the sow between mating and weaning.

Method B was therefore evolved to provide estimates of energetic efficiency by relating changes in the energy content of the sow and litter over gestation and lactation, or the whole reproductive cycle, to the observed sow and litter energy intake over the same period, the formulae being as follows:

The efficiency of energy recovery during gestation =

$$\frac{(W^{o} \times 420) + W^{CEg}\ \text{kcal}}{Ig \times 1814} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ 8$$

The efficiency of energy recovery during lactation =

$$\frac{(W^{s} \times 1055) - (W^{o} \times 420) \pm W^{CEl}\ \text{kcal}}{(Il + Ic)\ 1814} \quad \ldots\ldots\ 9$$

and the efficiency of energy recovery during the whole reproductive cycle =

$$\frac{(W^s \times 1055) \pm W^{CER} \text{ kcal}}{(Ig + Il + Ic)\ 1814} \quad \ldots\ldots\ldots\ 10$$

When expressed as percentages the values obtained through the application of these last three formulae provide estimates of the total energy recovery in sow and litter tissue per 100 units of observed feed intake.

Since, in method B, weight gains are considered as part of the total energy recovery, they are credited with their estimated energy content, 3312 kcal per pound, rather than 4925 kcal, as was the case in Method A.

RESULTS

The relevant details regarding weight changes and pigs born and suckled by the sows on the experiment are shown in Table 2.

TABYE 2. INITIAL WEIGHTS, FINAL WEIGHTS, NUMBER OF PIGS BORN AND SUCKLED

Sow No.	Litter No.	Wt at Mating lb	Wt at Farrowing lb	Gain from Mating lb	Wt After Farrowing lb	Gain from Mating lb	No. of Pigs Born	No. of Pigs Suckled
			High Condition at Farrowing					
127	1	200	333	133	310	110	6	6
120	2	376	494	118	451	75	9	9
122	2	306	424	118	385	79	8	8
106	4	424	517	93	486	61	10	8
102	4	368	475	107	428	60	10	8
Totals		1674	2243	569	2060	386	43	39
Means		334.8	448.6	113.8	412	77.2	8.6	7.8
			Low Condition at Farrowing					
126	1	236	315	79	286	50	7	7
119	2	300	374	74	330	30	9	7
121	2	342	404	62	368	26	9	8
117	4	400	437	37	395	— 5	14	10
107	4	414	460	46	423	9	8	7
Totals		1692	1990	298	1802	110	47	39
Means		338.4	398	59.6	360.4	22	9.4	7.8

As can be seen from Table 2, some of the low condition sows gained rather more than planned, and some of the high condition sows rather less.

The mean difference in gain between the two groups from mating to farrowing was 54 lb, while the difference when the gain was calculated

between mating and post-farrowing was 55 lb. This latter figure is a more reliable indication of true weight gain than the pre-farrowing weight. During the first few days after farrowing an attempt was made to standardise litter size, but the best that could be achieved, owing to the spread of farrowings, was an equal number of piglets suckled and weaned per group, as shown in Table 2.

The yield and the average composition of the milk produced by each sow during the last seven weeks of the eight-week lactation is shown in Table 3.

TABLE 3. INDIVIDUAL SOW YIELDS AND AVERAGE MILK COMPOSITION

Sow No.	Milk Yield	% Fat	% Prot.	% Lact.
	High Condition at Farrowing			
127	363	8.9	6.0	4.7
120	583	9.1	6.4	4.5
122	627	9.3	6.1	4.5
106	693	10.1	6.0	4.5
102	628	10.5	6.3	4.3
Totals	2894			
Means per sow	545.8	9.53	6.16	4.5
Means per piglet	70.0			
	Low Condition at Farrowing			
126	425	10.4	6.1	4.4
119	508	9.1	5.8	4.5
121	597	9.6	5.9	4.6
117	609	9.4	6.2	4.6
107	590	9.1	5.9	4.5
Totals	2729			
Means per sow	545.2	9.52	5.98	4.5
Means per piglet	69.9			

The average yield per sow, and the average content of fat protein, and lactose during successive weeks of the lactation are shown in Fig. 1.

The low-condition sows produced slightly less milk than those in high condition, the difference representing only 4 lb of milk per pig suckled. Milk composition was also very similar for the two groups, although the sows in low condition tended to produce milk of lower protein content.

The energy content of the milk from the two groups and the gross efficiencies of milk production are shown in Table 4.

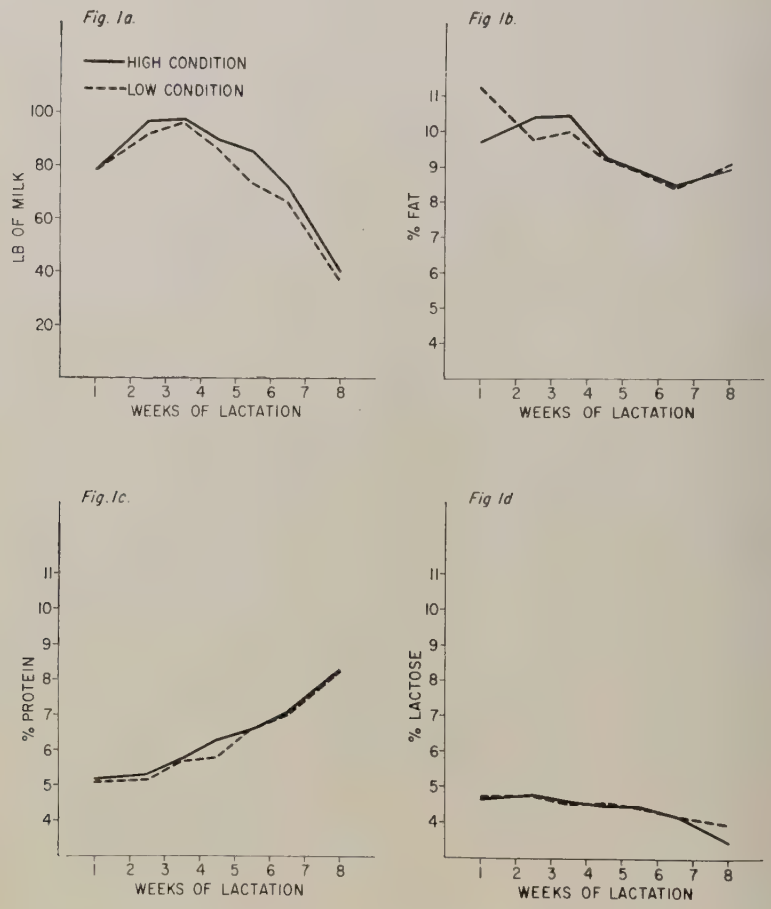

Fig. 1.—Mean yield and composition of the milk of the sows on the two treatments during successive weeks of lactation.

The low-condition sows produced less milk energy per sow and per piglet, they also lost less weight, presumably because the treatment during gestation left them with lower body reserves to mobilise for milk production. After losing an average of 8 lb in the first week and 54 lb during the last seven weeks of lactation, these sows were 40 lb lighter at weaning than at the start of the experiment, indicating that they possessed some mobilisable reserves at the time of the original mating. Examination of the weekly weights showed that both groups lost weight throughout lactation, that the rate of loss declined as lactation progressed, and that the low-condition sows lost weight at a lower rate over the period than did those in high condition. The weekly losses are shown in Table 5.

TABLE 4. THE ENERGY CONTENT OF THE MILK PRODUCED AND THE GROSS EFFICIENCY OF MILK PRODUCTION

(Energy values in therms)*

Sow No.	Energy Content of Milk	Sow Feed Energy Intake	Loss or Gain in Wt. lb	Energy Equiv.	Total Energy Intake Equival.	Gross Efficiency of Milk Production %
			High Condition			
127	222	386	— 27	89	475	46.7
120	364	497	— 67	222	719	50.6
122	393	452	— 70	232	684	57.5
106	456	459	—116	384	843	54.1
102	427	472	— 91	301	773	55.2
Total	1862	2266	—371	1228	3494	
Means per sow	372.4	453.2	— 74.2	245.6	698.8	53.3
Means per piglet	47.7					
Kcal/lb milk	643					
			Low Condition			
126	285	428	— 27	89	517	55.1
119	310	447	— 46	152	599	51.8
121	380	452	— 70	232	684	55.6
117	387	532	— 76	252	784	49.4
107	362	428	— 52	172	600	60.3
Total	1724	2287	—271	897	3184	
Means per sow	344.8	457.4	— 54.2	179.4	636.8	54.1
Means per piglet	44.2					
Kcal/lb milk	632					

* One therm = 1000 kilocalories.

TABLE 5. MEAN WEIGHT LOSS PER SOW DURING SUCCESSIVE WEEKS OF LACTATION

Condition at Farrowing	Mean Wt. Loss by Weeks (lb)						
	2	3	4	5	6	7	8
High	12.2	13.6	11.6	11.0	10.2	8.0	7.8
Low	8.4	9.4	9.0	9.0	8.2	5.4	4.8

In view of these data it is not possible to conclude that the sows in low condition at farrowing were completely depleted at the end of the lactation. The continued loss over the whole period, and the difference in the rate of loss between the two groups, suggest that the extent of the body reserves possessed by the sow at the onset of lactation affected the rate at which they were catabolised.

The results also indicate that it would be advisable deliberately to deplete sows of all body reserves prior to the start of an experiment such

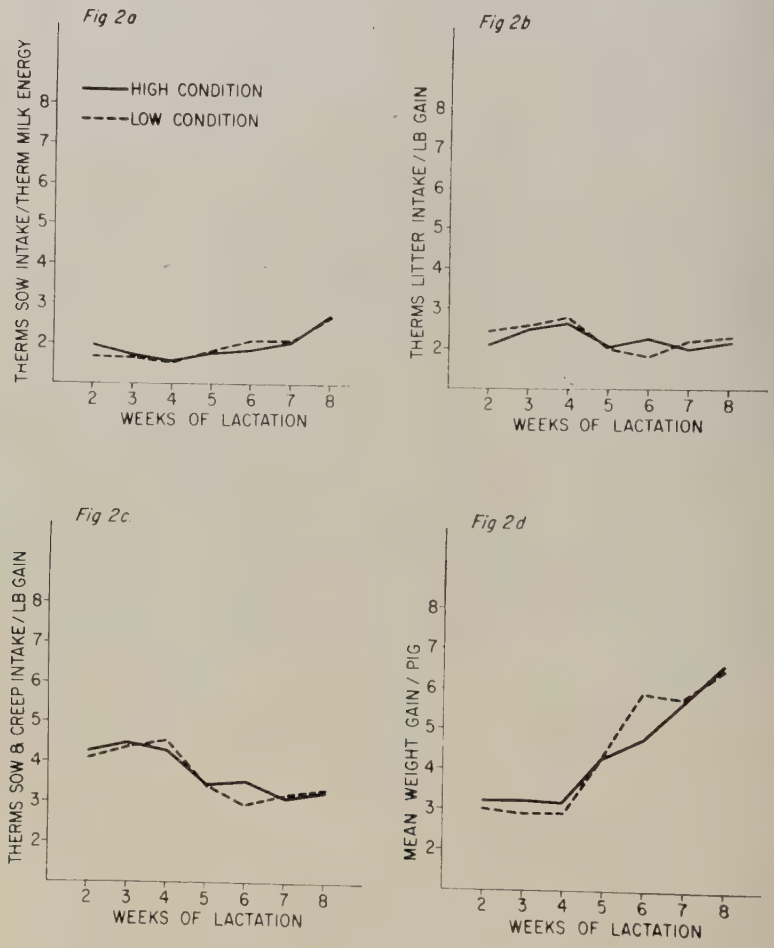

Fig. 2.—(a) Therms of sow feed energy intake equivalent (allowance being made for sow weight changes) per therm of milk energy produced. (b) Therms of litter intake from sows' milk and creep per pound of litter gain. (c) Therms of sow and litter energy intake equivalent per pound of litter gain. (d) Mean weekly gain per pig.

as this, so that the weight gains during gestation would then represent the stored energy available for use during lactation.

The gross efficiency of milk production was similar for the two groups, suggesting that, while body reserves last, the efficiency with which these reserves and feed intake are utilised for milk production is not dependent upon the degree of depletion to which the sow is subjected. The various measures of energetic efficiency calculated by weeks are illustrated in Fig. 2.

It is apparent that the efficiency of sow feed energy conversion to milk, of sow milk and creep feed energy conversion to litter gains, and of sow feed energy and creep intake to litter gains, were similar in every case for the two groups. It will be noted that in calculations involving litter gains, sow 126 has been omitted. This sow milked normally but her litter was unthrifty and consumed little from the creep, and after weaning the piglets were so uneconomic that they were eventually destroyed. It is unlikely that the unthriftiness of this litter was due to experimental treatment imposed on the mother.

The final litter gains over the seven weeks and the intake per piglet of metabolisable energy in the form of creep and sow milk are shown in Table 6.

TABLE 6. MILK ENERGY AND CREEP ENERGY INTAKE, AND GAIN PER PIG
(Energy values in therms)

Condition at Farrowing	No. of Sows	No. of Pigs	Energy Intake per Pig from		Total	Gain per Pig lb	Energy Intake per lb Gain
			Sow's Milk	Creep			
High	5	39	45.3	21.2	66.5	30.7	2.17
Low	4	32	42.7	25.6	68.3	30.8	2.22

TABLE 7. GROSS EFFICIENCY VALUES FOR THE LAST 7 WEEKS OF LACTATION

Treatment	Gross Efficiency of Milk Prod. (1) %	Gross Efficiency of Energy Conversion by Litters (3) %	Gross Efficiency of Lactation (2) %	Gross Efficiency of Sow Feed Energy Conversion* (4) %
High condition at farrow	53.3	50.9	30.7	26.0
Low condition at farrow	54.1	49.8	31.2	25.4

* In calculating these values creep energy intake and the energy content of the gains made by the litter as a result of creep intake have been excluded.

The small difference between treatments in milk energy available per pig was more than offset by the greater creep intake of the litters from the sows in low condition.

To summarise the levels of efficiency attained by the sows in the two treatment groups, Table 7 was prepared. The figures in parentheses beneath each column heading refer to the formulae used in calculating the values shown.

The gross efficiencies of gestation, lactation, and the reproductive cycle using formulae 5, 6, and 7, were calculated, omitting sow No. 126. The values are shown in Table 8.

TABLE 8. Gross Efficiency Values for Gestation, Lactation (8 Weeks) and the Whole Reproductive Cycle
(Energy value in therms)

Gross Efficiency of Gestation

	Condition at Farrowing	
	High	Low
No. of sows	5	4
Sow intake including grass	5497	3182
Energy equivalent of sow wt. changes	1901	295
Energy intake equivalent	3596	2887
Energy content of litters at birth	50	41
% efficiency	1.39	1.42

Gross Efficiency of Lactation

	Including Creep	Excluding Creep	Including Creep	Excluding Creep
No. of sows	5		4	
Energy intake during lactation	2597	2597	2123	2123
Energy content of creep	827		818	
Total	3424	2597	2941	2123
Energy content of sow wt. changes	1421	1421	934	934
Energy intake equivalent of sow and litter	4845	4018	3875	3057
Energy gain of litter, birth to weaning	1435	1020	1170	759
% efficiency	29.6	25.4	30.2	24.8

Gross Efficiency of the Whole Reproductive Cycle

No. of sows	5		4	
Energy intake during gestation	5497	5497	3182	3182
Energy intake during lactation	2597	2597	2123	2123
Energy content of creep	827		818	
Total	8921	8094	6123	5305
Energy equivalent of wt. changes	142	142	732	732
Energy intake equivalent	9063	8236	6855	6037
Energy content of weaned litter	1485	1070	1211	800
% efficiency	16.4	13.0	17.7	13.3

Briefly the values shown in Table 8 indicate that:

1. For each 100 therms of feed energy used by the sow for maintenance and litter growth during gestation, 1.4 therms were recovered as litter energy at birth.

2. For each 100 therms of energy available to the sow and litter, from offered feed and from the catabolism of sow body reserves, 30 therms were recovered in the increased energy content of the litter between birth and weaning.

3. For each 100 therms of energy available to the sow and litter from offered feed during gestation and lactation plus the energy equivalent of the difference in weight between mating and weaning, 17 therms were recovered as litter tissue energy at weaning.

TABLE 9. EFFICIENCY OF ENERGY RECOVERY OVER GESTATION, LACTATION AND THE WHOLE REPRODUCTIVE CYCLE
(Energy values in therms)

Gestation

	Condition of Sows at Farrowing	
	High	Low
No. of sows	5	4
Sow intake	5497	3182
Energy content of wt. changes	1278	199
Energy content of litter	50	41
Total energy recovery	1328	240
% efficiency	24.2	7.5

Lactation

	Including Creep	Excluding Creep	Including Creep	Excluding Creep
Sow intake	2597	2597	2123	2123
Creep intake	827	—	818	—
Total sow and litter intake	3424	2597	2941	2123
Energy content of litter gains between birth and weaning	1435	1020	1170	759
Energy content of wt. changes	—1421	—1421	— 934	— 934
Total recovery in sow and litter tissue	14	— 401	236	— 175
% efficiency	0.4	— 15.4	8	— 8.2

Reproductive Cycle

Sow and litter intake	9371	8094	6123	5305
Energy content of litter at weaning	1485	1070	1211	800
Energy content of wt. change	— 142	— 142	— 735	— 735
Total energy recovery in sow and litter tissue	1343	928	476	65
% efficiency	14.3	11.5	7.8	1.2

4. Over gestation, lactation, and the whole reproductive cycle, the sows and litters of the two experimental groups used the energy available to them with equal efficiency.

The values obtained using the second method of calculation (Method B, formulae 8, 9 and 10) are shown in Table 9.

The values shown in Table 9 indicate that: (1) during gestation 24 and 7 therms of energy were recovered as sow and litter tissue energy for each 100 therms of observed feed energy intake by the sows in the high- and low-condition groups respectively. (2) Over lactation 0.4 and 8 therms of energy were recovered as sow and litter energy for each 100 therms of observed sow and litter feed energy intake by the high- and low-condition groups respectively when the effect of creep feed intake was included. When the effect of creep feeding was excluded each 100 therms of observed sow feed energy intake resulted in a loss of 15 and 8 therms of tissue energy from the sow and litter. This negative energy recovery was due to the fact that the energy content of sow weight losses during lactation exceeded the litter energy gains resulting from the intake of sows' milk. (3) Over the reproductive cycle, each 100 therms of sow and litter intake resulted in a recovery of 15.1 and 7.8 therms of sow and litter tissue energy in the high- and low-condition groups respectively, when the effect of creep feeding was included and 11.5 and 1.2 therms when the effect of creep feeding was excluded.

General Discussion

Results of a previous study, Smith (1959b) have indicated that the milk energy yield of sows in high condition at farrowing was not reduced by a low level of nutrition during lactation. The sows in this earlier study exhibited the ability to buffer the effects of low intakes by drawing upon body reserves. In the present study an attempt was made to reduce the reserves of one group prior to farrowing (the low-condition group) to a point where continued milk production would result in complete depletion with a possible consequent reduction in yield.

The data indicate that (1) the sows considered to be in low condition did, in fact, possess unsuspected reserves; (2) these reserves were drawn upon at a relatively low rate over the whole lactation rather than being expended at a rapid rate in the early stages, and (3) the slight difference in yield between the two groups was probably a real treatment effect which would have been accentuated had the pre-treatment been more severe.

As has been mentioned earlier it would be advisable in future studies of this type to endeavour to deplete the sows completely prior to applying the experimental treatments so that the extent of the body reserves at farrowing could be more accurately assessed.

The efficiency estimates based upon the seven weeks of lactation shown in Table 7 are of the same order as those obtained in a previous study (Smith 1959b). In both experiments it has been shown that 50% of the energy intake of the litter was recovered as litter energy at weaning, while only 25% of sow intake equivalent was recovered in this form.

This finding re-emphasises the logic of early weaning as a technique for increasing the energetic efficiency of reproduction, and also indicates the possibility of improving the efficiency of the normal rearing methods if some means could be devised to increase the intake of supplementary feed by the suckling litter, or more precisely, to increase the proportion of the total sow and litter intake that is consumed by the litter directly from the creep.

The values obtained under method A, for gross efficiency of gestation, lactation, and the whole reproductive cycle, require some comment.

As shown in Table 8, 1.4 therms was recovered as litter energy for each 100 therms of metabolisable energy intake utilised by the sow for maintenance and litter growth during gestation. This value is based upon a number of estimates and calculations which are all subject to large errors. For this reason the estimated efficiency of gestation, as shown, should be regarded as little more than an indication of the extremely small prenatal energy requirement of the litter for growth as compared with the requirement of the sow for maintenance.

The gross efficiency of lactation, indicated by the recoery of approximately 30 therms of energy in the form of litter tissue per 100 therms of sow and litter energy intake equivalent (allowance being made for the energy derived from sow tissue catabolism) is a more accurate estimate than that for gestation since it is based on fewer and more soundly based assumptions. In the present study there is no indication that the pre-farrowing treatments have exercised any effect upon lactational efficiency. It is of interest to note that the reduction in the values obtained when the effect of creep feeding was excluded indicates that this practice increased the overall efficiency by 5%.

The gross efficiency of the reproductive cycle, 16.4 and 17.7 therms recovered as litter energy per 100 therms of sow and litter intake equivalent for the high- and low-condition groups respectively, while indicating the efficiency with which the energy available was utilised does not, however, provide any distinction between sow tissue energy stored and used during the current cycle and energy stored prior to the current cycle but used during it. In fact, both groups used body reserves which were laid down prior to the cycle covered by the present study.

It might be suggested that where weight losses during lactation exceed the gains during gestation, the excess loss should be debited at the rate of 4925 kcal per pound rather than 3312 kcal, since the former quantity of feed energy would be required per pound of weight recovery, in excess of maintenance, to allow the sow to regain her weight deficit in the course of the subsequent gestation.

The second method of calculating efficiency, method B, has provided values which differ materially between treatment groups.

Over gestation, 24 and 7.5 therms were recovered as sow and litter tissue energy for each 100 therms of observed sow intake including pasture, by the high- and low-condition groups respectively. This difference in efficiency may be explained as being due to differences in

the productive feed energy available relative to sow maintenance requirements. Whereas the sows farrowing in high condition gained 0.7 lb live weight per day during gestation, the low-condition group gained only 0.2 lb per day.

Both groups exhibited a positive efficiency over lactation when the effect of creep feeding was included, and a negative efficiency when the effect of creep feeding was excluded. In both cases the low-condition sows proved to be the more efficient. The lower efficiency of the sows in high condition was due to the greater weight losses which these animals suffered. There was, in fact, an inverse relationship between weight losses and efficiency, a relationship which was verified by calculation of the efficiency values for previous studies (Smith 1959a, b), and which may be explained on the basis of the data presented in Table 8. Here it was shown that, when the effect of creep feeding was excluded, only 25% of the sow feed energy intake equivalent was recovered as litter energy. It follows, therefore, that each 4 therms of body energy reserves expended by the sow, and debited against litter energy, was offset by an increment of only 1 therm of litter energy.

The efficiency values for the whole reproductive cycle were positive in all cases. The high-condition sows proved to be the more efficient. This finding can also be related to the magnitude of weight losses, the difference in mean weight between mating and weaning being only 8.4 lb for the high-condition group, whereas the four low-condition sows were on the average 40 lb lighter at weaning than at mating. Thus, in the case of the high-condition sows the large weight losses incurred during lactation were offset by the relatively large gains made during gestation.

These results when considered in conjunction with those from a previous study (Smith 1959b), suggest that over lactation there are two nutritional principles which need to be reconciled. Evidence has been advanced that sows fed on a sub-maintenance ration during lactation use the energy available to them more efficiently than sows fed on a high ration. On the other hand, sows which lose weight exhibit a poor total energy return for the feed energy invested in them.

In the present study, when the effect of creep feeding was excluded, the combined energy content of the sow and the litter at weaning was less than that of the sow alone immediately after parturition, despite the fact that approximately 520 therms of feed energy had been processed by the sow over the 8 weeks of lactation. There seems little point in feeding animals at a level which ensures the utilisation of a high proportion of the energy ingested, when the end result of the process is a net loss of energy.

When the energy recovery from the whole reproductive cycle is considered, it is evident that the sows that gained most weight during gestation showed the greatest energy return. It is apparent therefore that overall efficiency may be increased by providing more feed during gestation to build up reserves, or a higher intake during lactation so that the need for stored energy is reduced, or by a high feeding regime during both gestation and lactation.

The question then arises as to whether it is more efficient to increase the ration during gestation or lactation. Armsby and Moulton (1925) after summarising the results obtained from various nutritional studies, concluded that, for cattle, the feed that would produce 1000 calories of milk energy would only produce approximately 800 calories in body gain. These values relate to the net efficiency of lactation and growth, i.e. the efficiency of a productive ration.

The present data for the high-condition sows may be analysed in a similar fashion, using estimated values for maintenance. The results of this calculation indicate that the feed needed to produce 1000 calories of sow milk energy would produce 780 calories as body gain.

It is of interest also to note that the net efficiency of milk production, calculated from the present data, was 90%. Lodge (1957) estimated the net efficiency of two Wessex Saddleback sows to be 84.4% and obtained values as high as 87%, 102%, and 92.5% at various stages in his experiments during which the animals gained or lost weight. These net efficiencies are high compared with those for dairy cattle, which are of the order of 60% (Brody 1945).

It might not be coincidence, however, that the net efficiency of milk production of both cattle and pigs is approximately twice that of the gross efficiency.

While the above estimates of the relative efficiency with which the feed was used for milk production or body gain by the sow are extremely tentative, they are, together with the data derived from dairy cattle, sufficient to support the premise that extra feed given during lactaion to avoid loss in sow weight would be more efficiently used than the same amount of feed given during gestation to build up reserves.

If the sows in the present experiment had, in addition to their actual intake, been fed the energy equivalent of their weight losses, they would theoretically have maintained their weight during lactation. If for the moment, the effect of higher intake *per se* upon the efficiency of feed utilisation is ignored, the estimated efficiencies for the whole reproductive cycle would have been raised from 11.5% to 24% for the high-condition group, and 1.2% and 16% for the low-condition group.

The difference of approximately 8% between the theoretical efficiencies of the two groups would then be due to the greater weight gains made by the high-condition sows during gestation. It would appear, therefore, that while feed energy may be used more efficiently for milk production than for weight gains, it is also more efficient to feed a productive ration during gestation than a maintenance ration, and that sows that make large weight gains are more efficient than those that make small gains. It may be assumed that there is an economic upper limit to the feed intake and weight gains made, but the present data provide no information on this point. The only conclusion that can be drawn is that the group that gained 77 lb during gestation showed a greater energy return per unit of feed energy invested than the group that gained 22 lb.

A system of feeding that maintains the weight of the sow during lactation and allows for even moderate weight gains during gestation raises a number of problems. It is possible to allow sows to continue to gain weight during their first two gestations, since much of this gain is true growth. Beyond this point, however, sows that are maintained during lactation and increase in weight during gestation would soon become obese. This could, and almost certainly would, lead to re-breeding difficulties and clumsiness after farrowing with consequent high litter mortality.

If, on the other hand, sows beyond their third litters are fed maintenance ration during gestation to avoid obesity, the energy return per unit of feed would be reduced to zero over this period, or to the relatively small return represented by the energy content of the newly born litter. A further alternative would be to maintain sows in low condition at all times, thus reducing maintenance costs, and making possible the use of low-quality cheap feeds during gestation. This system would need to be modified just prior to farrowing to avoid the possibility of light litters at birth and high post-natal mortality.

Lastly, it is extremely difficult to feed sows sufficient during lactation to enable them to maintain their weight. This difficulty is accentuated under practical farm conditions in New Zealand where high summer temperatures depress appetite and a bulky ration, separated milk, is the main source of feed.

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